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MINUTES AND PROCEEDINGS
of the Thirty-second meeting of the
ARMED FORCES-NRC VISION COMMITTEE
April 2-3-4, 1953

Navy Electronics Laboratory

San Diego, California

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San Diego, California

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12. CDR. Dayton R. E. Brown announced that the Secretariat would distribute to Vision Committee members and other interested persons copies of a publication entitled Natural Illumination Charts (Report 374-1, Research and Development Project NS 714-100, Bureau of Ships), along with a sun's position calculator. Additional copies of this material are available from the Secretariat upon request.

13. Dr. Rudolf Penndorf presented a paper entitled "The Vertical Distribution of Mie Particles in the Troposphere." The text of the report is contained in the Proceedings. 60

14. Dr. H. D. Edwards presented a paper entitled "Day-Sky Brightness Measured by Rocket-Borne Photoelectric Photometers." The text of the report is contained in the Proceedings. 70

15. Dr. S. Q. Duntley presented a paper entitled "Military Visibility Problems." The text of the report is contained in the Proceedings 78

16. Dr. J. E. Tyler presented a paper entitled "Project Hook." The text of the report is contained in the classified Supplement to the Proceedings.

17. Dr. H. R. Blackwell presented a paper entitled "Recent Laboratory Studies of Visual Detection." The text of the report is contained in the Proceedings 86

18. Dr. Kenneth T. Brown made an announcement concerning a recent development of interest in connection with problems of visibility. A summary of this announcement is contained in the classified Supplement to the Proceedings.

19. The Committee made a tour of the facilities of the Visibility Laboratory of the Scripps Institution of Oceanography.

Saturday, April 4

20. Dr. Paul M. Fitts (Chairman), LCDR. Dean Farnsworth, Dr. Neil R. Bartlett, and Dr. Max Lund participated in a panel discussion entitled "Visual Display Problems in Electronics Systems." A transcript of the discussion is contained in the classified Supplement to the Proceedings.

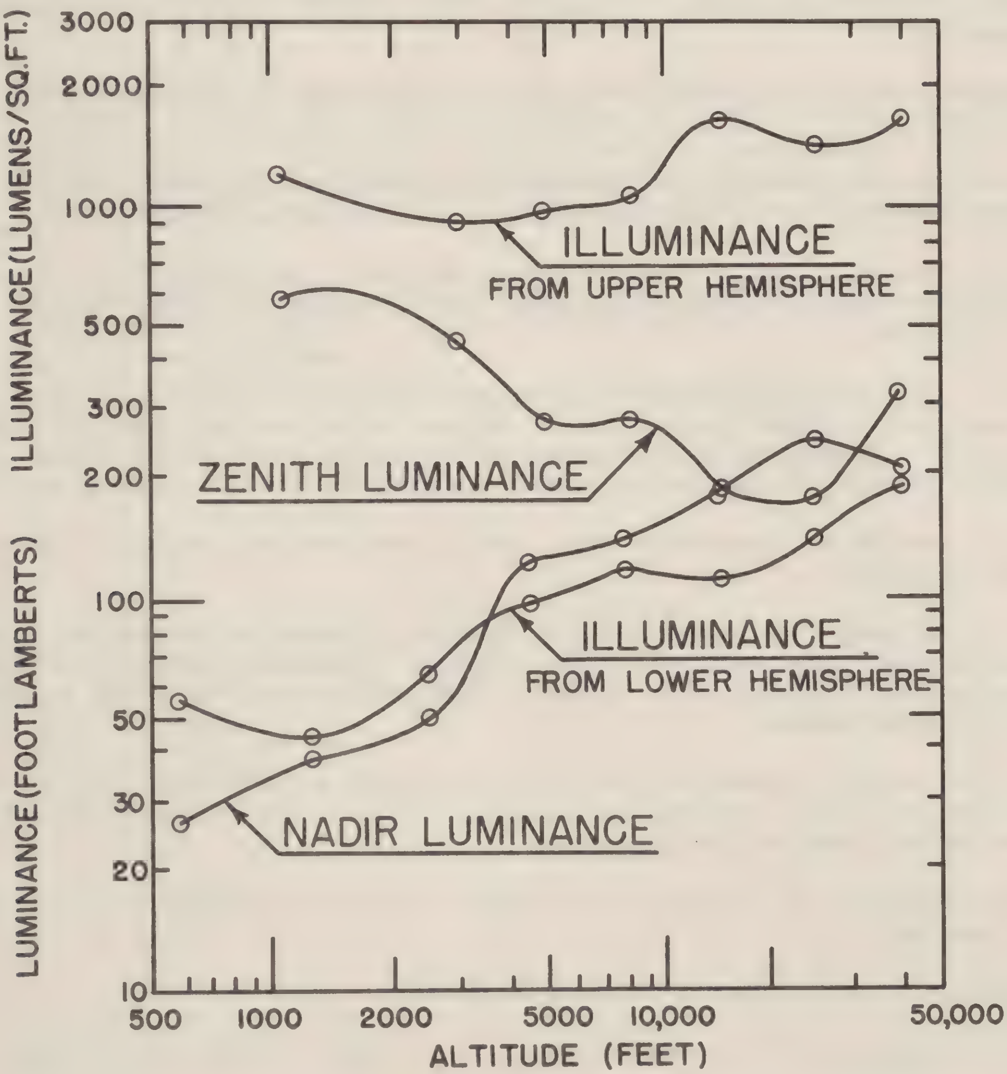
21. Drs. Theodore Dunham, Jr. (Chairman), S. Q. Duntley, H. K. Hartline, W. R. Miles, and Richard Tousey participated in a panel discussion entitled "Factors Influencing the Design and Use of Night Binoculars." A transcript of the discussion is contained in the classified Supplement to the Proceedings.

22. Dr. S. Q. Duntley (Chairman), Col. Jack Bristow, and Drs. Alphonse Chapanis, Theodore Dunham, Jr., H. K. Hartline, and Richard Nierenberg participated in a panel discussion entitled "Optical Aids for Visual Reconnaissance." A transcript of the discussion is contained in the classified Supplement to the Proceedings.

CORRECTION TO THE MINUTES AND PROCEEDINGS OF THE THIRTY-FIRST MEETING

Dr. S. Q. Duntley has submitted a correction to his "Report on the Working Group on Visibility at High Altitudes," which was published in the Minutes and Proceedings of the Thirty-first Meeting of the Vision Committee, November 20-21-22, 1952.

Due to an ambiguity in the numbering of the filters used on the B-36 flight last fall, the plot of illuminance and luminance vs. altitude, which appears on page 233 of the Minutes for November 1952, has to be revised. The revised diagram appears below.



Preliminary Report

A NEW ARMED SERVICES VISION TEST APPARATUS

Benjamin J. Wolpaw
Cleveland, Ohio

This suggested version of the "Armed Services Vision Tester" was designed with a number of objectives in view. First, it was considered advisable to start an entirely new development rather than attempt to modify or adapt older screening instruments to meet the testing situation imposed by the Armed Services. The next basic objective was to design an instrument as small and compact as possible that would be rugged, self-contained and easily transported.

Other functional requirements which were established at the outset of this project were:

1. To permit presentation of the specified Armed Services vision tests with a high degree of accuracy and at the test distances set forth in the specifications.

2. To keep the number of manipulations required of the operator to a minimum, to reduce the time required to train operators, and to cut down the time required to administer the test battery.

3. To provide an arrangement whereby all the presently specified targets (as well as others that might be added later) could be included within the instrument, thus eliminating the necessity of opening the target housing or of separate packaging of alternate targets. As a by-product of this, to seal the essential working parts of the instrument against dust.

4. To provide a considerably larger target field than was available in our previous screening instrument.

5. To do away with glass slides and thereby minimize the problem of target breakage. At the same time, improve the situation in regard to handling, storing, interchanging and cataloging of target combinations as might be required for various testing situations, such as military classifications.

The instrument occupies an area about the size of a letterhead. The base is 9-3/16" wide and 10-1/8" deep. The over-all height is 11-3/4". The weight is 13-3/4 lbs. without and about 24 lbs. with the carrying case.

The targets are all processed on 35 MM. film and 20 different tests can be accommodated on one reel.

Illumination is provided by a single small bulb.

The optical system will accommodate a P. D. range of from 55 to 75 MM.

The brightness of the white background of the Acuity and Depth Tests is 12 foot-Lamberts.

This instrument has several advantages over our previously recommended testing device in that it is smaller, considerably lighter, has one bulb instead of two; replacement of slides will be less expensive, and the cost is materially less.

How well it will perform remains to be seen.

A program to evaluate the instrument is now in the process of being set up. A working committee composed of Dr. Louise Sloan, Dr. Glenn Fry, the speaker, plus a representative of each participating organization will very shortly go to work. I hope that we can give you a second final report in the not too distant future.

Discussion:

Dr. Sulzman expressed interest in the modifications of the American Optical Company screening device. He also expressed some concern at the long delay already experienced in getting machine testing into the armed services, and wondered if the evaluation of the AO device would not increase this delay still further. Dr. Sulzman then asked whether the armed services had apparently accepted the idea of visual screening devices.

Dr. Wolpaw announced that some 200 Armed Forces Vision Testers had been delivered to the Air Force within the past two weeks and that there had not been sufficient time for reactions to become evident.

PROPOSED PLAN FOR EVALUATION OF THE FREEMAN ILLUMINANT-STABLE COLOR VISION TEST

Dean Farnsworth and Helen Paulson
Naval Medical Research Laboratory
U. S. Submarine Base

There are very few color vision tests available on the market today and most of these are not good. As we have long known, all polychromatic plates require the use of specific illumination or even the best will give misleading results. Therefore, it would be a decided advantage if a test were developed which could be used under any type of illumination ordinarily encountered. The closer the colors in the test lie to the red-yellow-green spectral locus, the less they are affected by the color temperature of the illuminant. Based on this idea, some years ago a test was created by Dr. Ellis Freeman, using pigments developed by Walter Granville, which was claimed to be illuminant-stable. I think that everyone who ever started to make a color vision test has discovered that it is a very impure type of test and involves many, many factors other than the actual colors on which everyone concentrates at the beginning. This first Freeman test proved to be faulty in design in many respects, as was stated by the Chairman of the Armed Forces Subcommittee on Color Vision in 1949.

Since then Dr. Freeman has put out a second edition and submitted it to the Bureau of Medicine and Surgery for evaluation as to possible Naval adoption. The Bureau has referred the matter to the Armed Forces Vision Committee, and the Secretariat has asked me to present briefly today the plan by which the Color Vision Laboratory in New London proposes to evaluate it. The original plan received the approval of Dr. Deane B. Judd, Chairman of the Subcommittee on Color Vision. It consists of three parts: The evaluation of the test's illuminant-stability, the evaluation of its reliability, and of course, an evaluation of its validity. The evaluation of its illuminant-stability will be organized in a Latin square design, employing a group of 180 subjects divided into six groups (25 normals and 5 color defectives per group); each group will be given the test under three different illuminants ("A," "C," and fluorescents) at two-week intervals with a systematic rotation of order. For an evaluation of its reliability, a different group of subjects will be used--105 all told, divided into three groups (25 normals and 10 color defectives per group); each group will be tested and retested under one of the three illuminants. For evaluation of validity all the subjects mentioned above will be given other standard sets of pseudo-isochromatic plates and the Medical Research Laboratory Color Vision Test Battery, which we proposed some years ago and which is now in general use in several laboratories; this MRL Test Battery consists of a series of tests of increasing difficulty which classifies the men according to five degrees of deficiency.

That is the plan which is proposed. It differs slightly from the original one because the very brevity of the test, which is claimed as one of its chief advantages, necessitated certain changes. Since there are only six plates, the subject can too easily memorize those plates with which he has any trouble--thereby making it impossible to test and retest the same subject several times under different illuminants. Therefore we have had to extend the test-retest period from days to weeks and we have had to use entirely new groups of people for the reliability evaluation and for the illuminant-stability evaluation.

MEDICAL RESEARCH LABORATORY COLOR VISION TEST BATTERY

CLASS	TESTS: Plates	TESTS: Navy Lantern	TESTS: Dichotomous-15
I (Normal)	pass	pass	pass
II (Mild)	fail	pass	pass
III (Moderate)	fail	fail	pass
IV-V (Severe and Complete)	fail	fail	fail

(Table should be read across)

Table 1

PROPOSED PLAN FOR EVALUATION OF THE FREEMEN ILLUMINANT-STABLE COLOR VISION TEST

I. EVALUATION OF ILLUMINANT-STABILITY: N = 180

	1st week under Ill.	3rd week under Ill.	5th week under Ill.
Test 25 normals and 5 color defectives	C	A	Fluor.
Test 25 normals and 5 color defectives	C	Fluor.	A
Test 25 normals and 5 color defectives	Fluor.	A	C
Test 25 normals and 5 color defectives	Fluor.	C	A
Test 25 normals and 5 color defectives	A	C	Fluor.
Test 25 normals and 5 color defectives	A	Fluor.	C

II. EVALUATION OF RELIABILITY: N = 105

25 normals and 10 color defectives: test-retest under A
25 normals and 10 color defectives: test-retest under C
25 normals and 10 color defectives: test-retest under Fluor.

III. EVALUATION OF VALIDITY: N = 285

The 225 normals and 60 color defectives will be given the M. R. L. Color Vision Test Battery, which will classify them as to type (Protan or Deutan) and degree (Class I, II, III, or IV-V). A correlation can then be made between Freeman's "pass-fail" and degree of defect in each type. Other sets of pseudo-isochromatic plates (A. O. Co. Plates, 1st Edition--present Navy selection; A. O. Co. Plates, 2nd Edition--present M. R. L. selection; new Ishihara Plate Edition; etc.) will be administered for comparison of results.

Discussion:

CDR. Farnsworth addressed to the group an inquiry as to what had happened to the recommendation made by the Vision Committee for a standard Armed Forces Color Vision Test.

CDR. Rand stated in reply that the Armed Services Medical Procurement Agency had just received the first formal bid on the color vision test and that copies of the test should be available within six months.

AN INVESTIGATION OF SOME RELATIONS AMONG SEVERAL MEASURES OF PATTERN DISCRIMINABILITY*

Oscar S. Adams and Paul M. Fitts
The Ohio State University

This paper contains the results of some research on pattern discriminability that is currently being conducted in the Aviation Psychology Laboratory of The Ohio State University. Our basic interest is in discovering the parameters of visual patterns that are the most important determinants of the ability to discriminate, or identify, one particular pattern from among a set of possible patterns. As one example, let us consider the task of the sonar operator who watches a visual display for several hours. He must quickly recognize and identify targets in the presence of visual noise and false returns. If an unusual visual pattern is detected among the reverberations following the ping, there are several decisions which he has to make quickly. He must decide not only whether it is a true target, but also what kind of target it is. He has to choose between alerting his captain at once, and watching the returns for a few more seconds in order to be more certain of his identification. The factors involved in making these decisions illustrate the general level of our work on pattern discriminability.

Before studying this problem, however, we must select techniques that will provide valid and reliable measures of the kind of discriminative behavior in which we are interested. The research reported here deals primarily with the question of methodology. Essentially we want methods for determining the effectiveness of the absolute recognition of visual forms under conditions in which the form has already been detected and the crucial step is to identify it immediately.

In searching the literature we have become increasingly aware of the fact that most studies have been concerned with variables affecting the absolute and differential thresholds. There are at our disposal a great deal of data which permit us to state rather confidently the probability of seeing a test light of a specified luminance and size under controlled experimental conditions. While it is true that a knowledge of such variables is basic to the understanding of visual discriminative behavior, we feel that it does not provide a complete picture. We still lack much information about the visual behavior that occurs when the stimulus is above the absolute threshold. It would be desirable to know more about the basic stimulus variables that affect the process of target interpretation and evaluation, the variables that influence the accuracy and rate with which an observer can assimilate and react to complex, supra-liminal information.

In many respects we have taken the same approach that has been used by such people as Patterson, Tinker, Luckiesh, Moss, Crook, and others (2, 4, 5) in their studies on legibility. Some of the research from the Johns Hopkins laboratory clearly fits into this framework, and we have followed it with interest. Our own interest, however, is directed toward many types of forms, patterns, and symbols, and is not restricted to typography and numerals. Most of the studies that we have encountered have dealt with very few types of visual patterns, and more often than not have been restricted to only one measure of performance. It is unfortunate that the most widely used patterns are the common geometrical ones. We should like to identify and know the effects of the broad psychophysical dimensions which encompass the customary geometrical patterns as well as any type pattern we should care to construct.

*This research was supported in part by the United States Navy under Contract No. N-onr-495(02) with The Ohio State University Research Foundation, monitored by the Office of Naval Research.

Also under consideration is the discriminability of targets that undergo intermittent or continuous change as well as static visual patterns. We are not the first to suggest that discrimination of a continuously changing target may not be the sum of the probabilities of detection under conditions of static display and discrete changes (1).

Our first approach to this problem has been to design a study in which several stimulus variables and performance measures could be studied simultaneously.

The Experiment

Apparatus

An apparatus was constructed to display the visual stimuli and to record 7 of the 11 measures that will be described shortly. It was designed as a rectangularly shaped box with a viewing hood protruding from one end. On top is a light-tight compartment containing a 40-watt incandescent light source which illuminates the inside of the viewing box when a double saw-tooth shutter is opened by a traveling wedge which is driven by a constant speed motor. With this arrangement it is possible to produce a continuous or intermittent growth of illumination from zero to approximately 10 foot-lamberts.

The rear wall of the compartment is 28 inches from the eye position of the subject, and contains a 1-1/4 by 2-1/4-inch aperture in which the stimuli appear. Located immediately in front of the aperture is a double-blade solenoid-activated shutter. The shutter can be opened by the experimenter or by a micro-switch located on the illumination control wedge. It is held open by the solenoid and closed by a voice key located on the subject's side of the apparatus.

On the outside and at the rear of the viewing box two rotating disks can be mounted so that stimuli can be presented for paired-associate learning. The exposure disk is driven by a constant speed motor, and makes one revolution every 10 seconds. The stimulus items are exposed for 2 seconds, the stimulus and response items together for 1 second, and a 2-second interval separates each presentation. The disk containing the stimulus items is positioned just behind the exposure disk and is operated by the experimenter.

The subject views the rear wall of the compartment binocularly through the viewing hood. Directly in front of his mouth is a microphone-type voice key.

Stimuli

The stimulus patterns are shown in Figure 1. They consist of variations of four basic stimulus shapes, and were designed according to four rules. First, the basic figures are relatively uncommon geometrical shapes having a rather low degree of meaningfulness. Second, they are symmetrical when symmetry is defined as congruency about either the vertical or horizontal axis

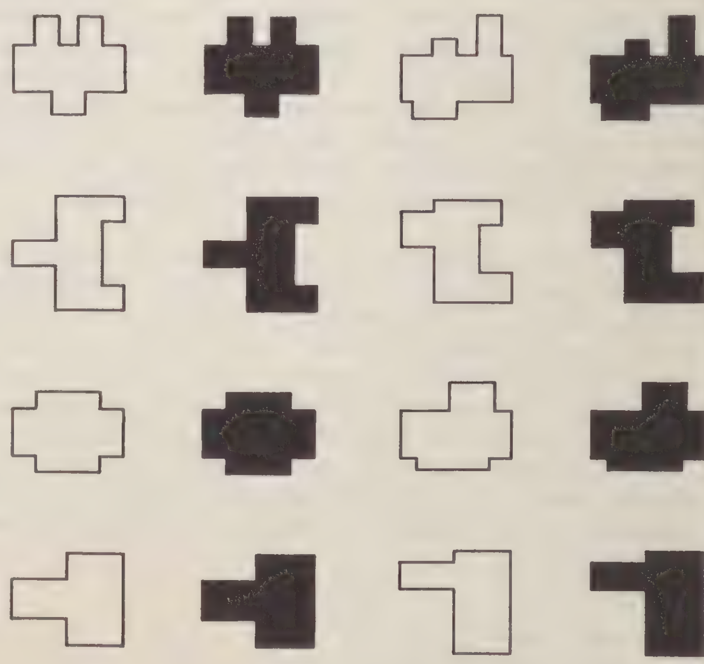


Figure 1. Stimulus Patterns.

(one-half of the figure is the mirror image of the other half). Third, all lines are straight lines, and all angles are right angles. And, fourth, all figures are closed and differ somewhat in complexity. Each of the four basic patterns was distorted so as to create a new asymmetrical figure equal to the original one in area. The resulting 8 figures (4 symmetrical and 4 asymmetrical) are represented as filled figures and as outline figures. With these two variations of the 4 basic figures, a set of 16 is produced. When viewed in the apparatus they subtended a visual angle of 1 degree and 32 minutes.

Procedure

Table 1 gives the eleven measures that were made on 16 subjects who served in the investigation. First, the acuity threshold, measured in visual angle, was determined for each figure by reproducing the figures for projection with a Bausch and Lomb Clason Acuity Meter. This measure was taken initially, and repeated at the end of the study. Next we recorded the number of trials required to associate an alphabetical letter to each stimulus figure to a criterion of five consecutive errorless trials. In addition to learning trials, the number of errors that occurred during learning were recorded for each figure. Following the learning, single figures were presented and the subject was instructed to respond with the appropriate alphabetical letter as quickly as possible. The figures were presented in a random order for a total of 25 times each under two levels of illumination. The "high" luminance measured 3.5 foot-lamberts, and the "low" luminance measured approximately .02 foot-lamberts. The exposure interval was controlled by the subject, and was measured by a chronometer which was started by the shutter and stopped by the voice key. In order to collect these scores it was necessary to space the presentations over a period of seven days. The response times for the first three days have been treated separately from the response times for the last three days.

Table 1

NON-PARAMETRIC TEST OF SIGNIFICANCES

Measure	χ^2_R	P
1. Learning Trials	18.44	.30
2. Learning Errors	34.24	<.01
3. Sorting Order	121.45	<.01
4. Sorting Time	104.29	<.01
5. RT (high-early)	33.35	<.01
6. RT (high-late)	62.25	<.01
7. RT (low-early)	52.07	<.01
8. RT (low-late)	71.90	<.01
9. Speeded Illum.	205.42	<.01
10. Pre-acuity	161.46	<.01
11. Post-acuity	149.25	<.01

Following the reaction time measures, a condition which we called speeded illumination was presented. In this the illumination was increased continuously and rapidly from a zero point to approximately .05 foot-lamberts in 10 seconds by the traveling wedge which controlled the saw-toothed shutter in front of the light source. The subject was instructed to identify the stimulus figure as soon as it could be seen, and the identification times were recorded over a period of three days.

Two measures of discriminability proposed by Sleight (6) have also been used. These are sorting order and sorting time. Each figure was reproduced eight times on small disks, and these were arranged randomly on a circular board. For sorting order the subjects were instructed to select the figures in order of prominence. The figures were then ranked according to the order in which the subject selected them. Sorting time consisted of recording the length of time taken to sort out the eight reproductions of each figure. These were presented randomly, and the subject always sorted from a total of 128 disks.

Results

All of the data were ranked by subjects by measure so that it was possible to compute rank correlation ratios between the measures. By doing this we have essentially eliminated

individual differences in absolute values. From Table 1 we see that a non-parametric test of significance of the ranked data for the 16 figures shows that the differences between the figures are significant beyond the 1% level of confidence for all of the performance measures with the exception of learning trials. In this latter case the differences are significant at the 30% level. From this we may conclude that there are significant differences in discriminability within our set of figures.

The next logical step in our statistical analysis was a factor analysis of the intercorrelations among the performance measures. Our approach here was, in general, similar to that employed by the Adjutant General's Office in their analysis of 14 tests of visual acuity (7). We had intentionally built at least two "factors" into the stimulus figures, and we were interested in knowing whether these would emerge under the conditions of measurement that we employed. At all times we have remained aware of the restrictions and limitations of factor analysis, and have used it as a statistical approach rather than as a final product of our experimental investigation.

Table 2 shows the original matrix of intercorrelations, the third residual table, and the three orthagonal factors that were extracted by Thurstone's centroid method. All of the correlations are rank correlations, and tend, therefore, to underestimate the degree of association between the variables. The range of correlations is very interesting. The highest value is between the pre- and post-acuity measures, indicating that the relative ordering of the 16 figures changed very little from before to after learning. There was, however, a significant over-all change in the size of the visual angle at which the figures could be identified, the post-acuity measures being significantly smaller at the 1% level of confidence.

The smallest intercorrelations exist between the acuity measures and the learning errors and sorting time, indicating essentially no relationship between the recognition thresholds of the figures and performance in a learning context when all of the figures were well above threshold.

The factor loadings illustrate nicely the relations between the various measures. Factor I has exceptionally high loadings on sorting order, speeded illumination, and the pre- and post-acuity measures. Factor II has its highest loadings on learning trials, learning errors, and reaction time under high illumination. The third factor has rather moderate loadings on sorting time, early reaction time under high and low illumination, and speeded illumination.

Discussion

The important thing to determine, of course, is what these factors mean. Factor I appears to be a rather general factor, but is particularly influenced by conditions in which the illumination is low and the discrimination depends on the amount of contrast. Table 3 shows that if we compare the sum of the ranks for the filled figures with the sum of the ranks for the outline figures, there are significant differences at the 1% level for sorting order, speeded illumination, pre- and post-acuity, at the 2% level for early reaction time under low illumination, and at the 5% level for late reaction time under low illumination. Inspecting the loadings on Factor I we find that these measures have the highest loadings on this factor. There is a rank correlation of .98 between these sums of ranks and the factor loadings of each measure. This factor has, therefore, been identified as a contrast factor, being associated with the differential brightness between the stimulus figure and its background.

Similar to Factor I, Factor II appears to be an internal factor. We find that the highest loadings occur on the two measures of learning and the two reaction time measures under high illumination. Moderate loadings occur on sorting order, sorting time, and the two reaction time measures under low illumination. If we divide the 16 figures into two

Table 2

INTERCORRELATION TABLE, RESIDUAL MATRIX, AND FACTOR LOADINGS OF 11 VISUAL PERFORMANCE MEASURES

Measure	INTERCORRELATIONS											FACTOR LOADINGS			h²
	1	2	3	4	5	6	7	8	9	10	11	I	II	III	
1. Learning Trials		.88	.80	.70	.92	.91	.85	.83	.58	.41	.44	.41	.90	.02	.98
2. Learning Errors	.00		.49	.71	.85	.83	.68	.68	.34	.13	.16	.12	.93	.02	.89
3. Sorting Order	.06	-.01		.45	.64	.70	.86	.87	.95	.88	.89	.90	.41	.10	.99
4. Sorting Time	.00	-.05	-.01		.74	.58	.61	.53	.35	.18	.26	.13	.71	.33	.63
5. RT (high-early)	.00	.04	.00	.01		.88	.80	.77	.51	.34	.35	.28	.90	.19	.92
6. RT (high-late)	-.04	-.02	-.03	.06	.00		.87	.88	.59	.42	.42	.43	.86	-.05	.93
7. RT (low-early)	.00	.03	-.04	-.05	-.03	-.06		.85	.78	.53	.70	.56	.67	.32	.88
8. RT (low-late)	-.04	-.01	-.02	.01	.00	.03	-.02		.78	.69	.69	.70	.64	-.02	.90
9. Speeded Illum.	.00	-.02	-.01	-.01	.01	-.02	.03	.00		.92	.95	.92	.22	.26	.96
10. Pre-acuity	-.01	.00	-.01	-.02	-.04	-.01	.06	-.01	.00		.97	.98	.01	.08	.97
11. Post-acuity	-.01	.00	.00	.00	-.02	.01	.03	.00	-.02	-.03		.99	.08	.00	.99
	RESIDUALS														

Table 3

SUM OF THE RANKS FOR OUTLINE (O) VS. FILLED (F) AND SYMMETRICAL (S) VS. ASYMMETRICAL (A) FIGURES

	(F)	(O)	(S)	(A)
1. Learning Trials	56.0	80.0	41.0	95.0***
2. Learning Errors	62.5	73.5	43.5	92.5***
3. Sorting Order	40.0	96.0***	54.0	82.0
4. Sorting Time	59.5	76.5	56.0	80.0
5. RT (high-early)	56.0	80.0	48.0	88.0*
6. RT (high-late)	54.0	82.0	45.0	91.0*
7. RT (low-early)	46.0	90.0**	53.0	83.0
8. RT (low-late)	47.0	89.0*	53.0	83.0
9. Speeded Illum.	36.0	100.0***	60.0	76.0
10. Pre-acuity	36.0	100.0***	66.0	70.0
11. Post-acuity	36.0	100.0***	65.0	71.0

* 3%.
** 2%.
*** 1%.

groups on the basis of symmetry, and sum the ranks for each figure for each measure, we find that the sum of the ranks gives a rank correlation of .91 with the factor loadings. Again the significant differences between the symmetrical and asymmetrical figures occur on the same measures that have the highest loadings on Factor II. This appears, therefore, to be sufficient evidence to identify the second factor as a "symmetry" factor.

It is interesting to note the differences in loadings of the reaction times under high and low illumination on both Factors I and II. When the illumination is high the discriminability of the figures is best predicted by Factor II, the symmetry or learning factor. Under low illumination conditions it is predicted by Factor I, the contrast or illumination factor, about as well as it is by Factor II.

It should be of considerable interest to service personnel that learning scores and speed of identifying a target after learning, both of which are of great practical importance in fleet operations, are measures which are included in the same factor, and are essentially independent of target brightness when the brightness is above threshold. In other words, the stimulus characteristics that help the operator in the initial detection of a target apparently are relatively independent of the stimulus factors that help him to identify it quickly.

Factor III presents a somewhat different picture than do Factors I and II. Rather than being an internal factor, it appears to be more of an external factor which is related to the time measure. This factor contributes its highest loadings on sorting time, speeded illumination, and early reaction times (both high and low illumination). The difference between early and late reaction times is revealed in the fairly significant drop in the size of the loadings for both high and low illumination. We are tentatively suggesting that this factor may be related to response times that are delayed either by weak association or by external viewing conditions. It does not appear when time is not used as a measure of performance, and it disappears in time scores when the response latencies level off or become approximately asymptotic.

It is interesting to notice the similarity between the factors that we have extracted from our matrix and those that were identified by the visual acuity study of the Adjutant

General's office (7). They concluded that the factors that were measured by their 14 tests were retinal resolution, brightness discrimination, form (letter) perception, and simple form perception. Our first factor seems to be closely related to their first two factors, and our second factor seems to describe the same characteristics as their last two factors.

One might further speculate as to whether Factors I and II strengthen the distinction that is often made between the terms visibility and legibility. Visibility studies emphasize accuracy of detection or identification with relatively unlimited response time. In legibility studies, however, the subject is instructed to work with time and accuracy criteria. The study of highway signs by Forbes and Holmes (3) illustrates nicely that different results can be obtained under these two conditions. If this distinction is real then we should be able to specify the characteristics of the stimulus which are most compatible with the information-handling capacity of the observer under any condition.

In conclusion we should like to point out that the approach that we have employed here appears to be a useful way of studying the kind of problem with which we are concerned. We plan to continue this type of investigation using other performance measures and other sets of dimensionalized patterns. In addition we are currently exploring the possibility of applying an informational analysis to visual discrimination behavior particularly in regard to the behaviors included in our second factor. One of the hypotheses that we plan to test is that the stimulus variable of symmetry is synonymous with the concept of redundancy as employed in information theory. So far this approach appears promising, and we hope that with it many of the problems of target identification can be brought into clearer focus.

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Discussion:

Dr. Uhlaner expressed interest in the use of factor analysis in the Adams-Fitts experiment. He emphasized the need for the inclusion of test objects in such an experiment whose design is based upon a priori assumptions of probable factors to be expected. For example, in the AGO factor analysis of visual acuity, the test objects were constructed on the basis of Vision Committee recommendations as to the probable critical factors in "visual acuity."

Dr. Uhlaner remarked that, since it takes at least three test objects to define a factor, it would have been desirable if the number of test objects could have been increased. Dr. Uhlaner also expressed his opinion that the inclusion of a learning index made it difficult for large numbers of subjects to be used. Dr. Uhlaner thought that the learning measure might well be left out, so that the number of subjects might be increased and the generality of the study increased.

Dr. Adams agreed with Dr. Uhlaner about the limited generality of a factor analysis based upon comparatively few test objects. He expressed the hope that in future studies he and Dr. Fitts would be able to increase the number of test objects.

Dr. Adams expressed his interest in retaining the learning score as an index of discriminability, though agreeing that the inclusion of this index made it very difficult to work with a large number of test subjects, such as 100 or more.

Dr. Adams agreed with Dr. Uhlaner that it is desirable to design test objects with specific factor hypotheses in mind, and noted that in the present study two such a priori factors were built into the test objects. These factors were contrast and symmetry. These factors did come out in the factor analysis. Dr. Adams noted that an a priori factor they called complexity was built into the test objects, but this failed to emerge from the factor analysis. Dr. Adams agreed that further research in this area should depend upon the design of test objects based upon a priori factors.

EXPERIMENTS ON THE SELECTION OF COLORS FOR COLOR-CODING PURPOSES

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INTRODUCTION

This experiment had its origin in a purely practical problem. At the present time, radar displays and vertical plotting boards in CIC's and air traffic control centers provide two-dimensional information--range and bearing--about aircraft in the vicinity. But the person who has to use the display ordinarily needs to have much more information about the aircraft which appear on it. In addition to the range and bearing of the target, he needs to know the altitude and speed, just to name two other items. Supplementary information of this sort must now be written in on vertical wall-plots. When the number of aircraft becomes very large, the amount of supplementary material which is thus added to the display often becomes confusing. It is difficult to tell which sets of numbers apply to what aircraft.

For this reason, people who are concerned with the design of displays for radar systems are considering other visual codes to convey supplementary information. Among these is color. It might be possible, for example, to code the altitude of aircraft in various colors, using reddish colors for low-flying planes and blue ones for very high-flying ones. (Color codes are, of course, useful in applications other than those mentioned here, e. g., on instrument panels.)

If colors are to be used for practical coding purposes of this sort, it is important to know what colors are usable. The available laboratory studies of color discrimination do not yield data which are directly applicable to this problem. In the first place, most laboratory studies use viewing conditions which are ideal, i. e., they provide for maximal discriminability. In addition, the usual criterion for discrimination is the j. n. d., or difference which is seen 50 percent of the time. But in practical coding situations, it is frequently important to select colors which will never, or rarely, be confused with each other even when there may be many colors present and when the viewing conditions are subject to the contaminating effects of chromatic contrast, after-images, and so on.

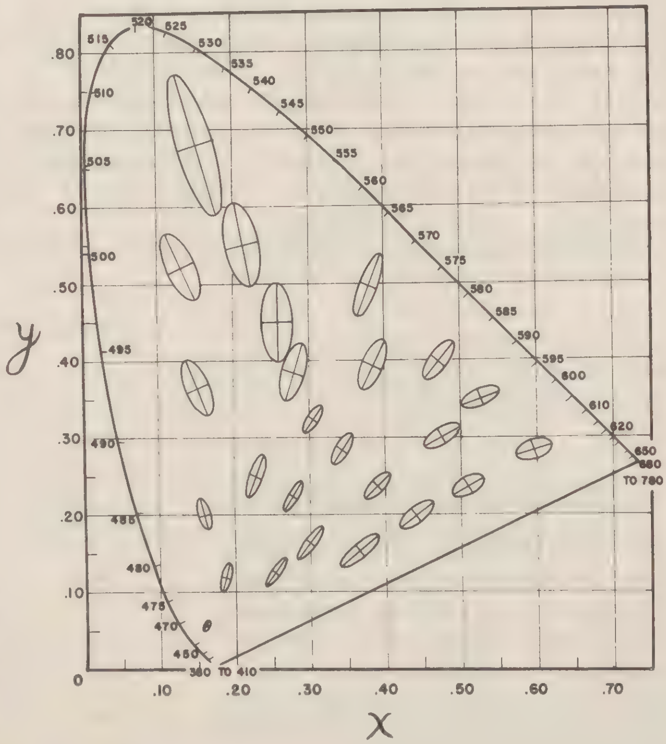

Figure 1. Distances from the center of any ellipse to a boundary represents chromaticity differences which are equally noticeable. The ellipses have been magnified 10 times. (After MacAdam, 1942)

*The research described in this paper was performed under Contract N5-ori-166, Task Order I, between the Office of Naval Research and The Johns Hopkins University.

Some Data on Discriminable Hues

A familiar set of data on color discriminability comes from the study by MacAdam (3). MacAdam investigated chromaticity differences which could just be perceived by the eye, and a part of his data appears in Figure 1. The distances from the center of any ellipse to the boundary of the ellipse represent equally-noticeable color differences. Actually, the ellipses in this figure are magnified ten times.

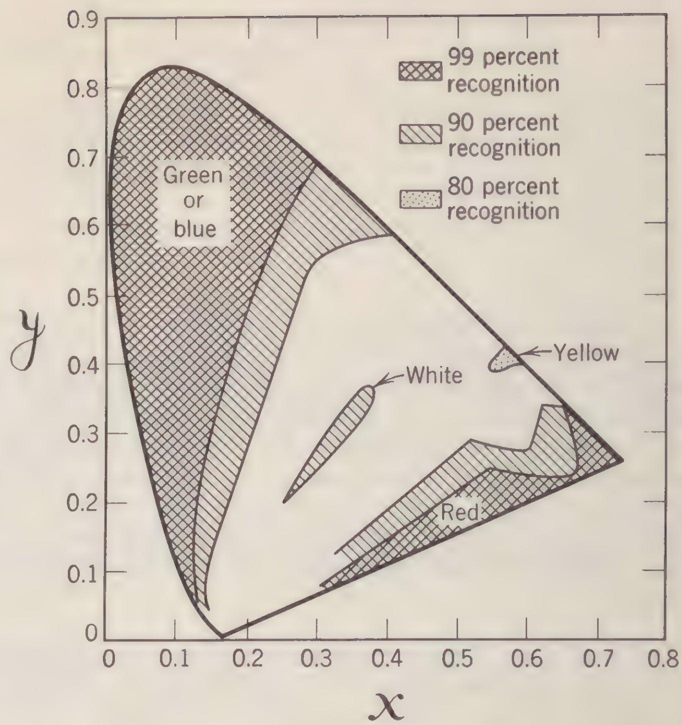

Figure 2. Locations of colors which were recognized with a high degree of accuracy at night. (After Hill, 1947).

A more practical kind of experiment on color discriminability is that reported by Hill (2). Hill's studies were concerned with the recognition of colored signal lights which are near the limit of visibility. He used a point source of light, against a background about equal to the starlit sky, with exposures of 1-1/2 seconds, and with two intensities of light --one which produced one mile-candle of illumination on the eye and another which produced two mile-candles. The observers knew where the light was and looked in that direction. Over 30,000 observations were made with 73 colored lights which the observers had to identify as red, yellow, orange, white, green, and blue. Some of Hill's findings are shown in Figure 2. Although these findings are not directly applicable for our purposes, it is interesting to compare Hill's results with those obtained by MacAdam in the laboratory. There are some superficial similarities between the two sets of data, but on the whole it is clear that the laboratory experiments could not have been used to predict the results which Hill obtained.

Purpose of This Experiment

The purpose of this experiment is to investigate color discrimination at various confidence levels when many colors are presented in a complex visual display. It is a continuation of related work done with spectral hues and reported elsewhere (1).

APPARATUS

A highly schematic view of the apparatus is contained in Figure 3. The entire assembly

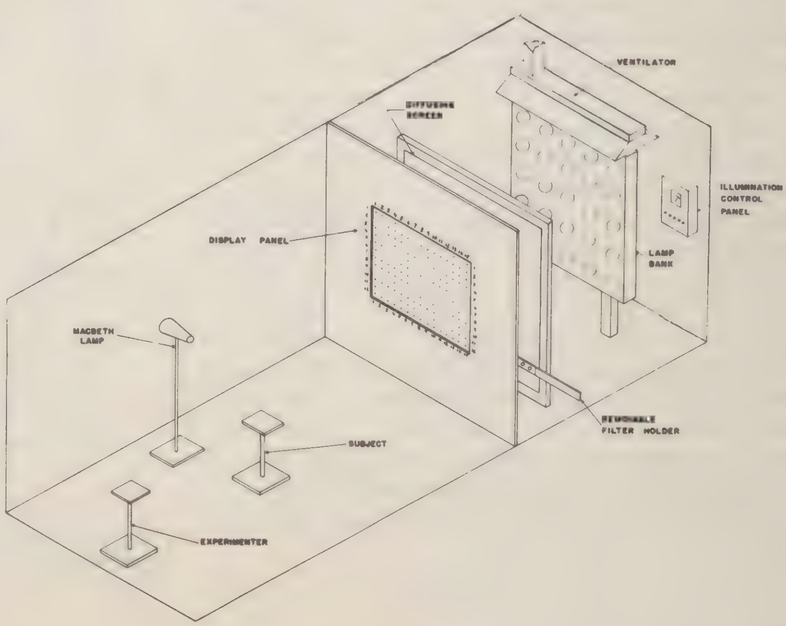

Figure 3. Highly schematic view of the apparatus and experimental rooms in this study.

occupies two separate rooms with a display panel built into the wall separating the two rooms. In one room a bank of 25 reflector-flood lamps illuminates a large diffusing screen. Light from the diffusing screen passes through a rack of filters behind the display panel. The lamps used in this experiment are all carefully calibrated for color temperature and are monitored through voltage controls. In addition, the lamps are re-calibrated periodically to take account of aging effects on color temperature.

We are using a total of 342 colored filters of which 58 are designated as standards. The CIE specifications of the filters and standards are shown in Figure 4. We tried to get as complete coverage of the CIE space as was possible to obtain with gelatin and glass filters. It is apparent, however, that we were not entirely successful since there are some fairly large, blank areas in Figure 4. Our filters include virtually all of the Corning and Wratten series plus combinations of these, theatrical gelatins, and such other filters as we could find.

The spots of light are 3/8 inch in diameter and the separation between the spots is 3 inches. The subject sits 6 feet from the display panel and at this distance the visual angle of each spot is 18 minutes in size. The visual angle subtended by the whole panel is 35 degrees. The luminance of the spots is 2.7 millilamberts and the illumination on the background is 0.014 millilamberts.

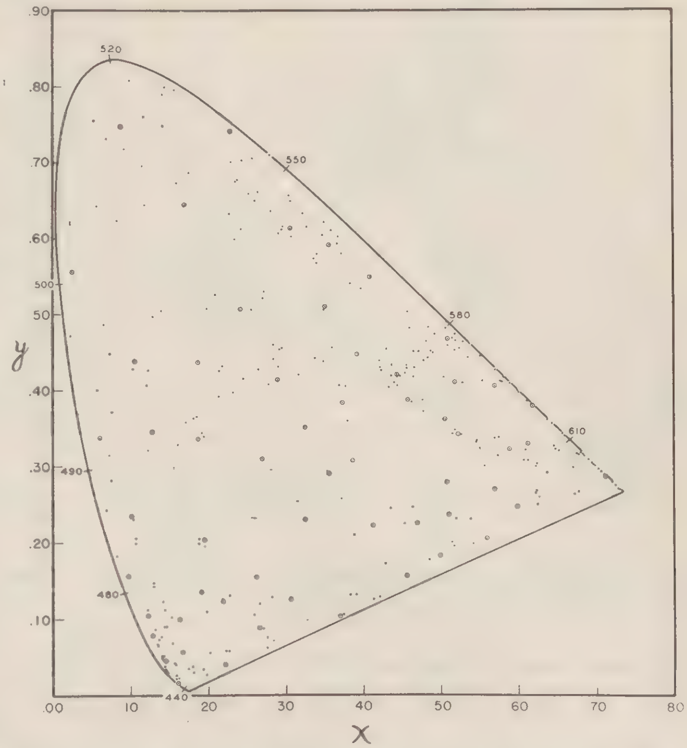

Figure 4. Locations of the 342 colors, and the 58 standards, used in this study. The standards are identified by the circled points.

PROCEDURE

For each subject there are four displays, each consisting of 171 colored lights assigned randomly to positions on a 45 x 36 inch board. Thus, each color appears twice for each subject. The standards are presented one at a time in the central position on each display. The subject's task is to select, from all the colors on the display, those which satisfactorily match each standard. Every standard is compared with every other color twice. Subjects are given unlimited time to make their matches and are carefully instructed to scan each row of lights systematically.

RESULTS

The data are analyzed by plotting each standard and its matches on the CIE diagram. Some typical results for 17 colors are shown in Figures 5 and 6. These data were obtained with 10 subjects, but it is our intention to run an additional ten subjects, making a total of 20 in all. The contour lines enclose all those colors which were confused with the standard a certain percentage of the time. For example, a contour line labeled 85 encloses all those colors which were confused with that standard 85 percent or more of the time. A contour line labeled 20 encloses all those colors which were confused with the standard 20 percent or more of the time. It is apparent from Figures 5 and 6 that the confusion contours for

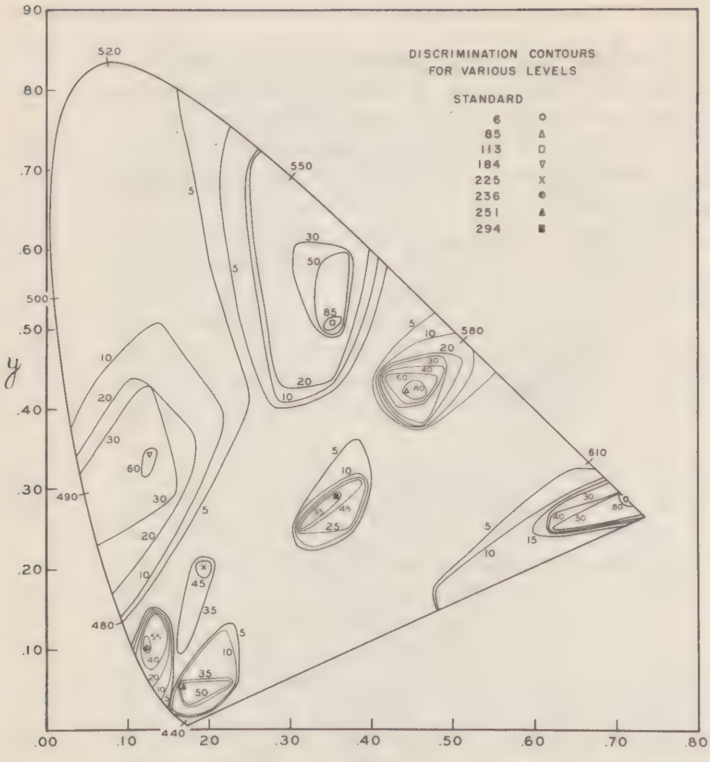

Figure 5. Confusion contours for eight standards. A contour line labeled 85, for example, encloses all those colors which were confused with the standard 85 percent or more of the time.

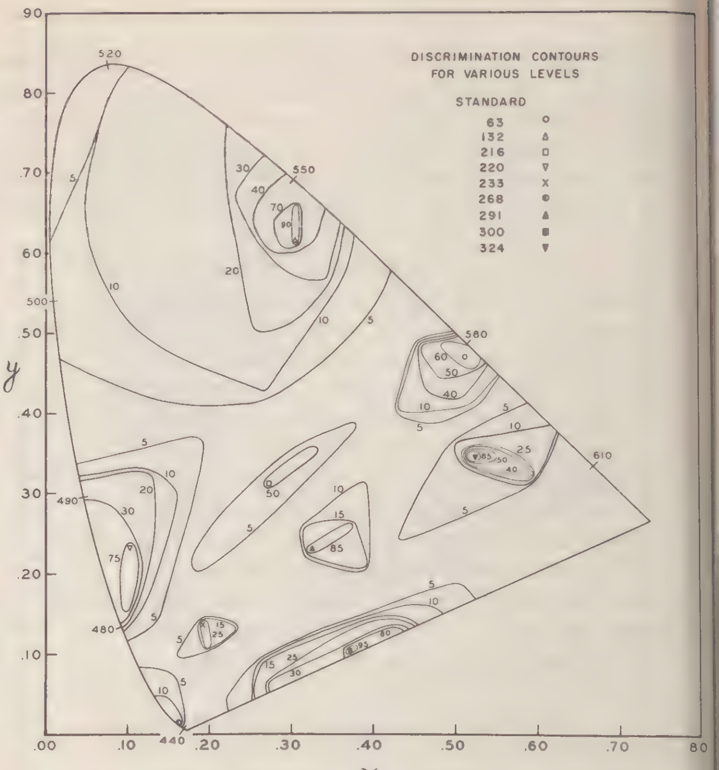

Figure 6. Confusion contours for nine standards.

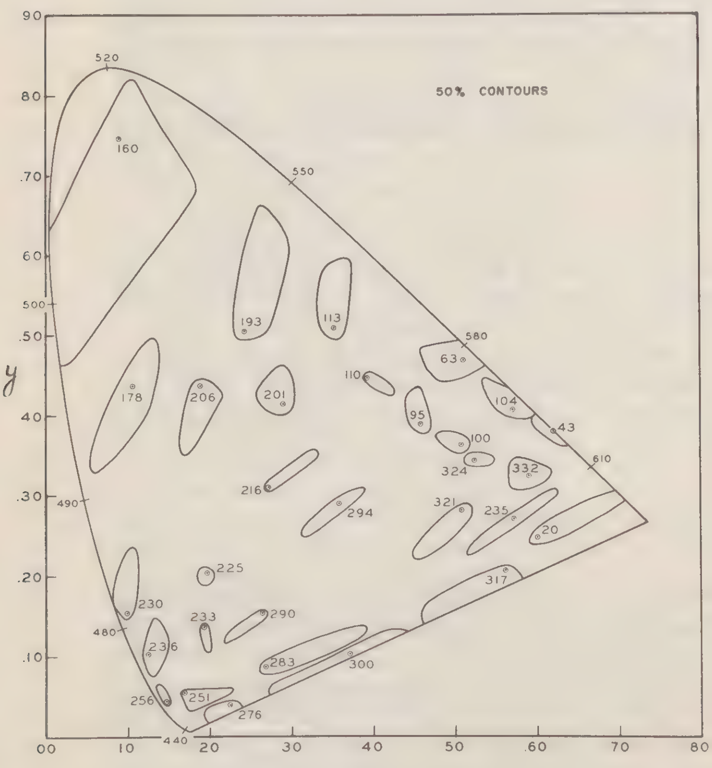

Figure 7. Fifty percent contours for certain standards. These lines enclose colors which were confused with the standards 50 percent or more of the time.

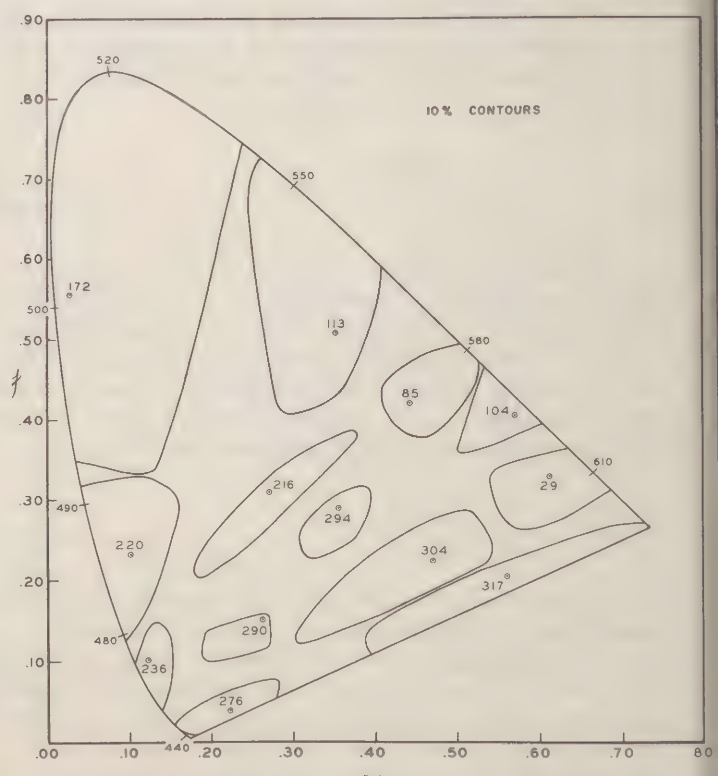

Figure 8. Ten percent contour lines for 13 standards. These lines enclose colors which were confused with their standards 10 percent or more of the time.

certain standards are very large indeed. In general, the contours are large in about the same regions of the CIE diagram as might have been expected from the earlier work of MacAdam and Hill.

In Figure 7 we have drawn certain 50-percent contours because these approximate the psychophysical criteria used in the typical laboratory experiment. Comparison of Figure 7 with Figure 1 shows that our contours are roughly 20 times as large as those found by MacAdam.

Figures 8 and 9 show 10-percent contours for certain standard colors. These are more realistic selections of colors for color-coding purposes. It is interesting to note that in both Figures 8 and 9 the maximum number of contours we could include, without overlapping, was 13. This suggests that if the designer of equipment wants colors that will not be confused more than 10 percent of the time about 13 colors are as many as he can expect to use. We should also stress, however, that these data are not yet complete since they are based on only half of the subjects we intend to use.

Individual differences in this experiment are quite large. Some sample contours for our most-discriminating, and one of our least-discriminating, subjects are contained in Figure 10.

DISCUSSION

For an experiment of this sort, it is important to inquire into the criteria the subjects used in making matches. Subjects were instructed to pick out matches for the standard which appeared in the center of the display. Each was told that the matches had to be of the same color, and he was instructed to decide for himself what constituted a "match." After the tests were over, subsubjects were interviewed to discover, "What are your criteria of a match?" Some typical responses are these:

Subject A: "Should have exactly the same components."

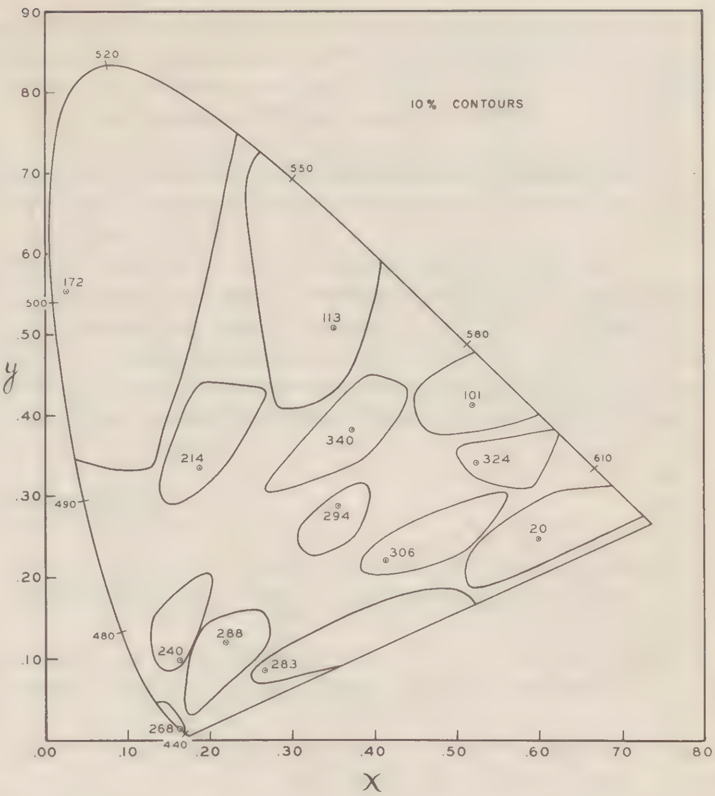

Figure 9. Ten percent contour lines for another selection of 13 standards.

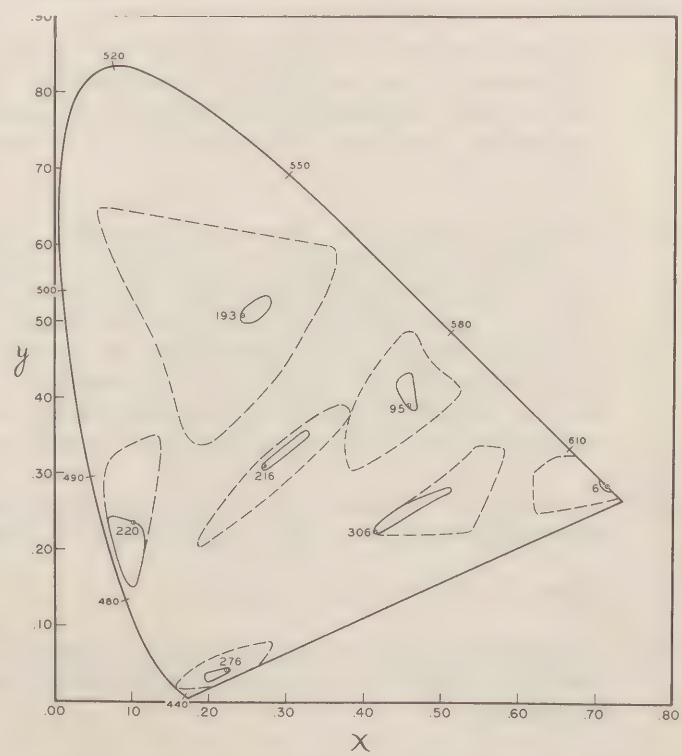

Figure 10. The solid lines show certain contours for the most-discriminating subject in this experiment; the dashed lines are for one of the least-discriminating subjects.

Subject B: "If there was no difference I could analyze, it was a match."
Subject C: "The colors must be identical, no difference."
Subject D: "The colors must be exactly the same."
Subject E: "There should be no disparity in any characteristic."

It appears, therefore, that our subjects were attempting to be as discriminating as possible in this experiment even though each was allowed to establish his own criterion.

The very large sizes of our confusion contours are undoubtedly accounted for by the conditions of our experiment. Ours is perhaps as confusing a visual display as will ever be found in practice. Colors must be compared when they are sometimes widely separated, and they are viewed under conditions which produce dazzle, after-images, successive contrast, and simultaneous contrast. These are, however, precisely the conditions under which colors of this sort would be seen if they were to be used on realistic displays.

REFERENCES

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2. Hill, N. E. G.: The recognition of coloured light signals which are near the limit of visibility. Proc. phys. Soc., Lond., 1947, 59, 560-574.

3. MacAdam, D. L.: Visual sensitivities to color differences in daylight. J. Optical Soc. Am., 1942, 32, 247-274.

Discussion:

Dr. Fry inquired concerning the effect on results such as those presented by Dr. Chapanis of changes in the background illuminant. He wondered if Dr. Chapanis hoped to predict results obtained under different illuminants from the present results, or whether a study of this sort would have to be repeated for every possible background illuminant.

Dr. Chapanis replied that this particular point had concerned him and that he was not sure to what extent it would be necessary to repeat this study for every conceivable illuminant. Dr. Chapanis stated that the particular conditions of the present study were selected to be as much like those of practical interest as possible, so that at least the study would have applicability to practical problems, if not generality. The room illumination in the study was approximately one-tenth the luminance of the targets and was, in quality, approximately equivalent to artificial daylight. The room illumination was sufficiently low that there was barely enough light to write by.

CDR. Farnsworth inquired as to whether the luminance difference between the targets and the background was sufficiently great so that there was irradiation.

Dr. Chapanis replied in the negative.

CDR. Farnsworth noted that the angular subtense of the targets was sufficiently small so that Dr. Chapanis might have expected to find some evidence of small subtense tritanopia.

Dr. Chapanis replied that they were, of course, aware of this possibility and had evaluated the data for evidence of small subtense tritanopia. However, no evidence of this kind of color confusion had been found.

Dr. Riesen expressed interest in the large individual differences found by Dr. Chapanis, and asked if Dr. Chapanis had any hypotheses to account for these differences.

Dr. Chapanis replied that he did not believe the individual differences to be due to differences in color discriminability per se. Each subject had been given a complete battery of color vision tests and each had been found to be "color normal." Dr. Chapanis expressed his view that the differences between subjects depended upon differences in criteria as to what constituted a discriminable difference.

Dr. Riesen then asked if Dr. Chapanis had any idea of the subjects' ability to identify colors by name.

Dr. Chapanis replied that the experimental design had deliberately avoided requiring the subject to reply in such a way that color-naming ability was involved, because of the semantic complications resulting from such responses.

DISPLAY-CONTROL COMPATIBILITY

Franklin V. Taylor
Naval Research Laboratory

The work to be reported consists of a series of demonstration-experiments performed by Drs. William Garvey and William Knowles of the Naval Research Laboratory. Dr. Arnold Small of the Navy Electronics Laboratory first employed the word "compatibility" in the manner of this report and Dr. Paul Fitts and co-workers of Ohio State University laid the groundwork for the present experiments. In his work, Fitts demonstrated clearly that the effectiveness of a display (control) was influenced markedly by the nature of the control (display) with which it was combined. This interrelationship between displays and controls was referred to as "compatibility." In his experiment, Fitts showed that the best display (when combined with a compatible control) became the poorest display when it was combined with a control with which it was highly incompatible. Further, the data indicated that the operation of a poor display (control) could be improved by combining it with a poor but compatible display (control).

Since the displays and controls used by Fitts were unrealistic, it was thought desirable to attempt a demonstration of compatibility with displays and controls similar to those in actual use. Consequently, signal light displays and pushbutton controls were built and tested. The display-control systems used are represented in Figure 1. System A consists

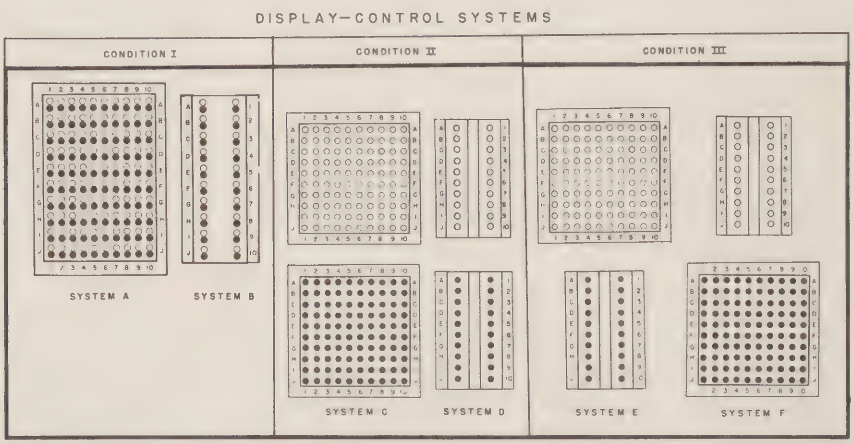


Figure 1

of a 10 x 10 matrix of signal lights with pushbuttons immediately below each light. When a light comes on the subject merely presses the adjacent pushbutton. System B consists of two columns of ten lights and associated pushbuttons. In this case one light is turned on in each column to signal a letter-number combination, and the button immediately under each light must be pressed.

System C consists of a 10 x 10 light matrix and a separate 10 x 10 pushbutton matrix, while System D consists of a double column of lights for the display and a double column of pushbuttons for the control. For systems E and F the displays and controls of C and D are employed in different combination.

In terms of Fitts' interpretation of the concept of compatibility, systems A and B would be the most compatible of the six systems, C and D the next most compatible, while systems E and F would be incompatible. Tests were run day after day on six U.S. Navy

enlisted men on all six systems. The average length of time required for a response to a signal was measured. The results are graphed in Figure 2. (The curves for systems G and H are to be neglected since these systems are not germane to the discussion.)

It is clear that the most compatible systems, A and B, permit the fastest responses, and that the incompatible systems, E and F, give rise to the maximum delay. Thus, Fitts' findings are supported when displays and controls are used which are somewhat realistic. Secondly, it is evident that though the subjects improve with practice on all combinations, the more compatible the systems, the less the subjects learn. This indicates that compatibility is more important for beginning operators than it is for experts. However, that compatibility is still important for well-trained subjects is shown by an effect obtained on the 16th day. On this day and the following, the subjects were required to perform their tasks as before, but in addition, they had to count auditory clicks and call out the number when they were introduced unpredictably during the sessions. This task was intended as a distraction, and that it was, is shown by the rise in all six graphs. It is noteworthy, however, that distraction has a greater effect upon the incompatible conditions than upon the compatible arrangements. This argues for the importance of matching displays and controls in military equipment since distractions are manifold during combat operations.

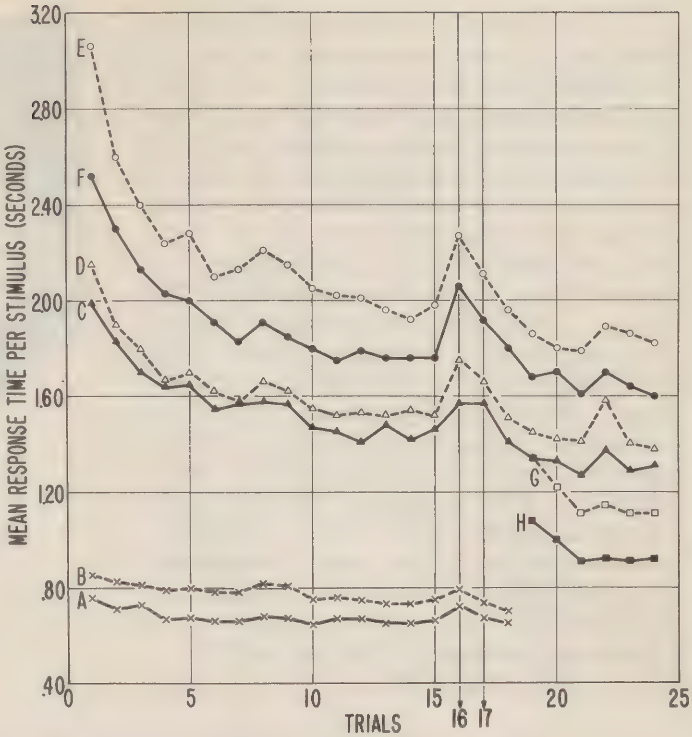


Figure 2

It seems reasonable to account for the findings relative to compatibility in terms of the degree of complexity of the mental processes involved in transforming the information provided by the display into an appropriate response. According to this argument, compatible display-control arrangements permit the subject to perform a simpler translational process than do the incompatible combinations. Stating it another way, incompatible systems may require more "mental steps" of the operator in passing information from display to control than is the case with compatible arrangements.

Internal evidence provided by the experiment makes it possible to check this reasoning. An analysis of the decoding and encoding processes used with system C suggest that the information is carried over differently from display to control when the signals occur on the periphery of the display than when the center of the matrix is involved. It would seem that it might be possible for the subject to grasp directly the spatial location of a signal occupying a peripheral position on the matrix and to find and press the corresponding key without going through any reading process. However, this would seem to be quite impossible in the case of lights near the center of the display. To identify a signal arising from the central region of the matrix, it would seem quite necessary to read off the letter and numeral designating its position and to repeat this process in reverse when locating the appropriate pushbutton on the control matrix. One would predict, therefore, that the response times to signals arising from the central portions of the display would be longer than those to lights occupying the peripheral locations.

In Figure 3 is presented a photograph of a three-dimensional model constructed by erecting columns for each cell in the matrix, proportional in height to the average response time measured for that cell in condition C. It can be seen that the response times to signals arising from the periphery of the matrix are considerably less than the response times to central portions of the display. Actually, the longest average response times are approximately double those measured for the outermost cells. Thus, the hypotheses that different means of coding information are employed for central and peripheral portions of a matrix display-matrix control system is supported. This, in turn, lends credence to the more fundamental idea that compatibility is a reflection of the extent to which the mental processes intervening between stimulus and response are simplified.

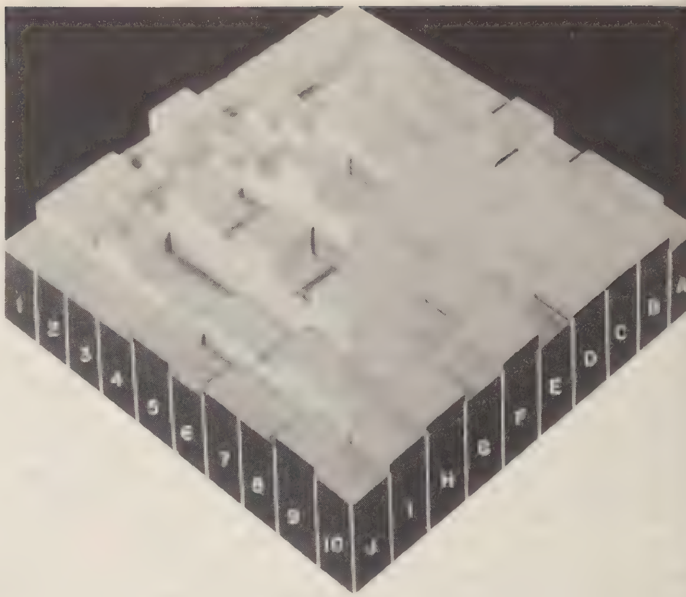


Figure 3

A further check on the explanation of the central-peripheral effect was provided by a test run with the matrix-matrix system modified by the inclusion of horizontal and vertical reference lines so drawn that they divided the display and control into four 5 x 5 matrices. It was reasoned that if the short response times observed for the peripheral signals were the result of the simplified method of coding which could be employed as a result of the spatial reference provided by the boundary, the addition of reference lines crossing at the center might reduce the central response times comparably.

Figure 4 shows a three-dimensional model representing response times for condition C modified by the addition of reference lines to the display and control. It is evident that the times no longer peak up in the center. Actually, four smaller peaks, more or less centered within the four 5 x 5 matrices into which the whole is divided by the reference lines, make their appearance. The apparent increase in peripheral column height seen in Figure 4 is probably due to the fact that the tests done with the modified system C were performed on different, and generally slower, subjects than those used in the original experiment. A repeat in which equated groups of subjects were employed for the comparison between the original and modified system C has been performed but the results have not yet been fully analysed. They do show, however, that after both groups had received 15 practice trials, the group working with the added reference lines averaged a full half second faster than the subjects operating the unmodified system.

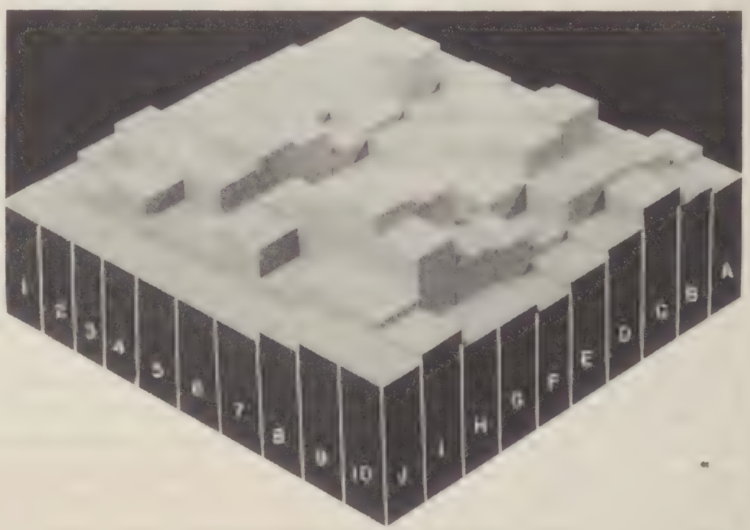


Figure 4

Taken all together, the results of these demonstration-experiments indicate the importance of compatibility in the design of displays and controls and, further, they suggest that the benefits derived from compatibility are best accounted for in terms of increased simplicity of the mental processes intervening between the signal and the response to the signal. Thus, compatibility appears to furnish one striking illustration of the efficacy of the much more general principle of so designing displays and controls that they require the least of the man.

RESEARCH AND DEVELOPMENT PROGRAM OF THE HUMAN FACTORS DIVISION

Arnold M. Small
Navy Electronics Laboratory

Those of us who had any part in the planning of the afternoon program for you are quite sensitive to time and therefore we have attempted in some of the materials we put in your hands this morning to reduce the amount of verbal presentation on points that we would like you to have before you go on the tour this afternoon. Primarily, what we would like to say in the next few minutes is calculated to make it possible for you to put in to the larger setting of our Division's work those specific things that you will see and hear about this afternoon. After I have spoken for a few minutes, I am going to ask each of the Branch Heads in the Division to tell you something a little bit more explicit about their work.

The way in which we prefer to present information about our Research and Development Program is to have you become directly acquainted with the specific tasks which we are carrying on. We realize, however, that there are many of the things that we are doing in the Human Factors Division that do not directly relate to interests in vision, so that we're taking a short time this morning before noon to talk mostly about them. The things that you will see this afternoon, therefore, are those that we believe are of more direct interest to you as people interested in vision.

We think that some of you, because of your personal interests, may wish to get in touch with our people doing other than visual work, and therefore we have provided you with a copy of our organization chart with names in the appropriate boxes. (See Appendix.)

The Navy Electronics Laboratory is a research and development laboratory under the management control of the Bureau of Ships. Its mission is broad and reads as follows:

Conduct research, development, and tests, as authorized by the Bureau of Ships, in the application of electronics to the Navy's operational needs in such fields as radio, radar, sonar, and weapons effects, including studies in the related fields of science and engineering, such as oceanography, electromagnetic radiation, sound, and the instrumentation for and analysis of environmental and human factors; provide consultative service and sea test facilities as authorized for the Fleet, for Navy contractors, and for other agencies of the Department of Defense.

The activities in the Laboratory are therefore understandably diversified. Running through a large part of the Laboratory's work are problems in the area of human factors. These are the concern of all, but are the objects of study, experimentation, and analysis by the Human Factors Division.

This setting, we find, provides a very stimulating atmosphere for our work and sets the stage for joint prosecution of work with the other divisions in the Laboratory. This, and other functions of the Human Factors Division are indicated in the appendix to these remarks. There is, of course, some research and development work that is unique to our Division. This is exemplified in the functions indicated on the last two or three pages of the appendix. However, since the Branch heads will speak more about these later, I will mention examples of areas in which cross-organizational efforts occur. These include, among others, Harbor Defense, Submarine Guided Missile Launching and Control Centers, Picket Submarine Electronic System, Electronic Trainers, ASW Communications, Sonar Target Classification and Sonar Systems Evaluation. Such work is carried on by joint teams made up of people from the Human Factors Division, the Systems Division, and Equipment Development Division.

Joint efforts of our Division are not restricted, however, to groups within the Laboratory. In their introductory remarks, both Captain Gambling and Mr. Maxfield mentioned the joint activity already under way with Dr. Duntley and his Visibility Laboratory. In addition, there has recently been established in San Diego and housed at the Electronics Laboratory, the Personnel Research Unit (NAVPRU) a field research unit of the Bureau of Naval Personnel. This group has responsibilities that articulate with work in our Division, especially with respect to training and certain aspects of psychophysics, where they carry on at the point at which we normally would stop. Joint teams and other methods of cooperative work are already under way and will increase. These two additional operating units in our midst we believe augur well for really joint efforts in the Navy's work.

The work that is listed under Item 3 in the functions of the Division—"The furnishing of consulting and engineering application services to the Bureau of Ships and its contractors" —is an important feature of our work. It puts us in continuing contact with the Bureau engineers responsible for electronic development research and development and with the large number of commercial contractors associated with them, including RCA, GE, Raytheon, Bendix, DuMont, Bell Telephone Laboratories, Westinghouse, Melpar and many others. We find that this, along with contact with the Fleet, provides us with the very best direct information and understanding that we can possibly get of human factor needs and problems to assist us in planning the work that should be done in support of the Navy at sea and onshore. Thus, you can readily understanding that part of our continuing training program for our personnel is a plan for sending our people both to technical schools and to the Fleet for significant periods of time. Whether it be riding destroyers, submarines, aircraft carriers or planes, our people are expected to come back with a comprehensive picture, documented as well as possible, with statements and preliminary analyses of observed problems, with possible studies and recommendations on the problems, and with a wider acquaintance with the Navy people themselves and their statement of needs as they see them in the field of man-machine operations.

The nature of our work is such that it covers a wide spectrum of activity with respect to the divisions and subdivisions of research and development work. I think, however, that the gamut is rather well illustrated in the demonstrations of our visual work that you will see in the tour of our Division. I would like you to remember that there is a similar range of research and development activities in our other fields. This would be true, for example, of audition.

I think it would be fair to state that about 25% of our effort is devoted to what might be called basic research. It would be more than that if you want to include supporting research under basic research. There is a good deal of misunderstanding possible when we use these words, "basic," "applied," and "supporting" research and I do not mean to be trying to make something of the difference. I personally believe that there is very little, if any, difference as long as it is good research. The difference lies chiefly in the attitudes and insights of the researcher. But something like 20-30% of our efforts, I think, can reasonably be described as basic research work in human factors. An additional 10 or 15% might come under a category of the shorter-term, "immediate answer" type of effort which is calculated to produce answers that are sorely needed now. Work with our Systems colleagues and those in the Equipment Development Division constitute probably another 25% and the remainder includes the type of work in our field that might be called development—such things as training materials to be used with training devices, consultation and application efforts, human engineering guide development, and research instrumentation.

Now I wish to introduce the Branch heads in succession, who will tell you something about their work. First, Mr. Robert Gales, head of the Psychophysics Branch.

* * *

Mr. Gales: I will attempt in this ten minutes to give you a thumbnail description of who we are in the Psychophysics Branch, how we work and on what problems we work. There are 16 professional personnel in our Branch, about equally divided between psychologists, mathematicians, engineers, and physicists. By equally divided, I mean we have seven psychologists and nine divided among the other three fields. Our work is primarily in audition, directed in two fields—sonar and voice communications. Our sonar work comprises the majority of our effort and involves both work on auditory and visual presentation of sonar information. The technique which is ordinarily used in our research and evaluation is that of simulation in the Laboratory of a specific job.

For some time it has been apparent in working with equipment which functions at sea, particularly sonar equipment, that, in order to run a study which finally results in additional basic knowledge, you need to control the parameters. This cannot be done at sea, or can be done only with great difficulty at sea. We found that by making recordings and bringing them back to the Laboratory and then controlling the human factors parameters, we are able to get reproducible results and assess the relative importance of the various parameters. In many cases we are able to simulate the tasks by using artificial noise generators and signal generators. In other cases we have to bring back recorded materials in order to be assured of an adequate reproduction of the task in the Laboratory.

Now to describe a few of our specific problems. In sonar the majority of our effort has gone into studies of methods of presenting sonar information. We have compared various displays--among others, aural, oscilloscopic, and the chemical range recorder which leaves a permanent trace. In these studies we come up with several types of data. First is a direct comparison under controlled conditions of these displays, which information goes back to the Bureau of Ships to be used in their design work. We also come up with information as to what elements in the signal seem most important, what types of filtering are possible to enhance certain properties of the signal to make it more detectable. The third area is that of threshold values and the factors that seem most important for training. These laboratory type studies pay off well in all three of these directions.

Another display which we are now studying and which you may see in your tour is the stroboscope as a detector of sonar signals. This is a new application as far as we are concerned and it appears that it has great promise, giving a correlation type of display for the detection of periodic signals in the presence of random noise.

Another study, one which is extremely active right now, is the study of the role of the various cues to classification of underwater echoes. One of our greatest problems in sonar now is that many underwater objects other than submarines produce echoes which appear to be very similar to the echoes from submarines. You will hear and see more about this this afternoon, but we have a very active program determining what are the important cues, what properties of these echoes are the most discriminating as between submarine and nonsubmarine targets, what effect does training have on the discrimination, how best to present these cues—visual, aural, or combination, and what type of visual display, and how best to integrate the information about the target that we get from different sources. For example, one operator may be getting information from a chemical recorder which shows us a plot of range vs. time for the target. Some other operator, perhaps in the same sonar room, is getting information as to depth, another operator will be listening to the echo, etc. It is important that we co-ordinate all of this information to come up with the single estimate of the target's identity in as short a time and as accurately as possible.

We have recently run an evaluation study which compared three different makes of chemical recorder papers. These are chemically sensitized papers which leave a permanent trace and are used in recording sonar range. We used psychological techniques to get an effective measure of a minimum detectable signal under controlled conditions for these three papers, and we were also able to get an estimate of dynamic range on the three papers under controlled conditions.

We are currently engaged in a study of various devices to come up with recommendations for a system for getting accurate turn-counts on screw sounds picked up over sonar gear.

In the field of voice communications we are studying various message loads, including competing messages and content, various filter conditions, and various noise conditions, to determine optimal techniques for handling these voice communication problems.

Finally I can only mention problems in binaural listening—signal detection, time discrimination; detection of multi-pitch signals; and special ship noise problems.

* * *

Dr. Small: I now would like to ask Mr. Carl Beyer to speak about the work in the Psychological Measurements Branch of which he is head.

* * *

Mr. Beyer: The work of our Branch is primarily training-oriented being tied up with the Bureau of Ships' responsibility to support the training activities and the Fleet in promoting the effective use of their shipboard electronic equipment. Our Branch is primarily concerned with the training problems associated with sonar and radar. To carry on this work, we have roughly 12 psychologists, two military training specialists, and some other present support through contractual assistance.

The work of our Branch falls under three general categories, namely, training devices, training materials, and study of performance and training requirements set by new Navy electronic equipment.

Insofar as training devices are concerned, there are two categories with which we have worked quite a bit. One of them is a procedural type trainer. By that I mean the training of a person to fire up his equipment, read and interpret the dials and indicators, and manipulate controls to get the maximum amount of correct information out of that equipment and thence to the officers who must process it and take action accordingly. In the case of sonar, this involves the use of visual displays on scopes and aural presentations through loud speakers or earphones. The sonar equipment can either be on surface ships or on submarines.

These procedural type trainers, as we design them, are fitted to simulate electronically the sounds that you would hear or the sights that you see through these equipments if they were at sea. A normal installation might consist of ten actual shipboard equipment control stacks, such as an operator uses in performing his job, which are fed synthetically by these simulation devices. Thus the student ashore has the actual part of the equipment which he must learn to operate activated in a way compatible with its actual operation at sea. Then there is a separate station in addition to these ten individual student booth stations where one instructor supervises the instruction of all of the ten students in his class. At this station he knows what the correct answer is, he knows what each student is doing through repeated information, and he knows exactly what problem is being presented. Incorporated with each device is some sort of scoring mechanism which gives an indication of at least one aspect of the operator's performance. We are doing more work in this latter area as time goes on.

The way in which these devices are worked on is rather interesting and unique insofar as other activities in the country doing this type of work are concerned. We share the responsibility for these training devices with a group of engineers from the Special Equipment Branch of the Equipment Development Division. We work continuously with them throughout the entire development process and they with us. At one time, for example, when we spell out the training requirements for this particular device, we are primarily

cognizant, and they assist us. In the preparation of engineering specifications, they are cognizant and we assist them. In the later phases after the actual hardware has been built, we feel that it is particularly important to see that the user knows the details of the functional performance and training capabilities of this device and knows how to get the most out of it. So we indoctrinate the personnel at these training activities in the use of this equipment, work with them in the development of a proposed training program, and write an instructor's manual for the trainer.

The other type of trainer, aside from this procedural type, is the recognition trainer. Recognition, as in sonar and radar, we define as that type of activity on the part of the operator which requires him to detect and interpret aural and visual presentations. With the trainer, he records his response in an automatic way for the instructor in front of the class. Thus, if you present a recording of the sounds made at sea under actual operating conditions and a student says this is a submarine or is not a submarine, he can record that response immediately and the instructor can then see immediately who understands the problem and interprets correctly. We use recognition, then, in this sense, that the operator can recognize what he has in the presentation and can make the appropriate decision as to what its importance is and what its category is.

The second area of interest in our Branch concerns training materials, and this is primarily for sonar work. As you may know, the job of the operator on a piece of sonar equipment is probably somewhat more difficult than that of a radar operator in that he does not have a standard or clear-cut indication of when he has the target. It requires a great deal of experience and training and also the analysis of a variety of cues to be able to decide whether what he has detected is a sub or not a sub and to be able to track that suspected submarine. So we have an extensive program under way, involving ships and submarines, during which we go to sea under actual controlled operational conditions and make recordings, scope photographs, and video recordings on magnetic tape of sonar presentations. These are brought back to shore, edited and developed into a systematic set of materials for training purposes. This program was designed according to findings derived from a series of research studies carried on by the people of our Laboratory. The studies involve such considerations as the difficulty of learning the various tasks, most appropriate mode of presenting these materials to the students so that the maximum amount of learning takes place in the minimum amount of time, retention, etc. A part of the most urgent work under this program is in connection with the target classification program. The sonar operator must classify with skill and with surety, because there is a terrific expense involving the firing of weapons on false targets, and also while you are doing that you cannot be protecting a convoy. We have done some work on presently known cues for target classification and there is an experiment under way at this time which will be described to you in part in one of the stops on your conducted tour. These training materials, I might add, will possibly be used on board ship eventually for refresher training, and in a variety of training activities in the Navy, over and above Fleet Sonar Schools where the principal sonar training is carried on. In connection with this program, as I mentioned, we have a large library and a wide variety of materials obtained under controlled conditions and they are available to other naval activities or commands for use in connection with any type of research where they might be applicable.

The third area of our activity is concerned with the study of new electronic equipments being produced for installation in the Navy to determine the nature of human performance required, the probable training requirements to make it possible, and recommendations and military specifications for trainers which may be needed to provide the required training.

* * *

<u>Dr. Small</u>: Our Instrumentation Staff will not have an opportunity to report to you so I would like to introduce Mr. John Leonard, Head of that Staff, at this time. We regard

his work as one of the most important links in our operations and as extremely valuable, critical, and well-done.

Now may I introduce Mr. Thomas Glenn, who will speak about the work of our Visual Detection Branch.

* * *

Mr. Glenn: The Visual Detection Branch has recently moved to the Laboratory from the Bureau of Ships and is assigned to the Human Factors Division. Most of the Branch functions will be found in the last paragraph of the last page in the appendix. In addition to those functions, we conduct observational operations and measurements from aircraft, from ships, from submarines, against aircraft, ships, submarines or land-based targets. We are also engaged in detection and environmental studies and we assist CDR. Brown in the evaluation of concealment designs before they are applied or after they are applied to elements of the Fleet. In general, we collect quantitative data that is pertinent to visual or photoelectric detection, we gather or analyze instrument design data, and we spot check under realistic operating or fleet conditions the calculations which Dr. Duntley and his Scripps Visibility Laboratory Staff are doing. These calculations involve the detection thresholds of naval and military targets. We are the point of linkage between the Human Factors Division and the Scripps Visibility Laboratory.

Some of the problems that we are engaged in involve range or depth computations, hours of profitable search for a specific target in a given geographical area, with known sun and moon positions, evaluation of currently applied paint to various elements of the Fleet. Also, every once in a while, somebody will buttonhole us in the corridors and say, "We understand you people have some sun charts. We'd like to know how wide to make the overhang on our front porch so that the sun doesn't get into the living room in the summertime." We do not overlap the functions that have been specifically assigned to Dr. Duntley's group, but rather supplement his work or assist him.

Finally, we are called upon to evaluate specific research instruments which have been designed by Dr. Duntley's group from the point of view of their possible operational use in the Navy. Among these are the photoelectric detector, sea-state meters, etc. The evaluation is for the purpose of providing an effective transition from research apparatus or laboratory apparatus to an engineered prototype for Navy use. The human factors in the transition from research apparatus to prototype apparatus will be exploited to the highest degree, so that the prototype will be well engineered from the human as well as from the other standpoints.

* * *

Dr. Small: Before I turn the floor over to Dr. Lund, I should like to express our pleasure in having you here and to encourage you during your stay to interact with us on technical and professional matters to the fullest extent possible. Fresh points of view, different approaches to measurement problems, etc., are matters of importance in our scheme of things, which leads us to consider visitors to our Laboratory as participants in our work rather than just onlookers.

Dr. Max Lund is head of our Human Engineering Branch, and now he has the floor.

* * *

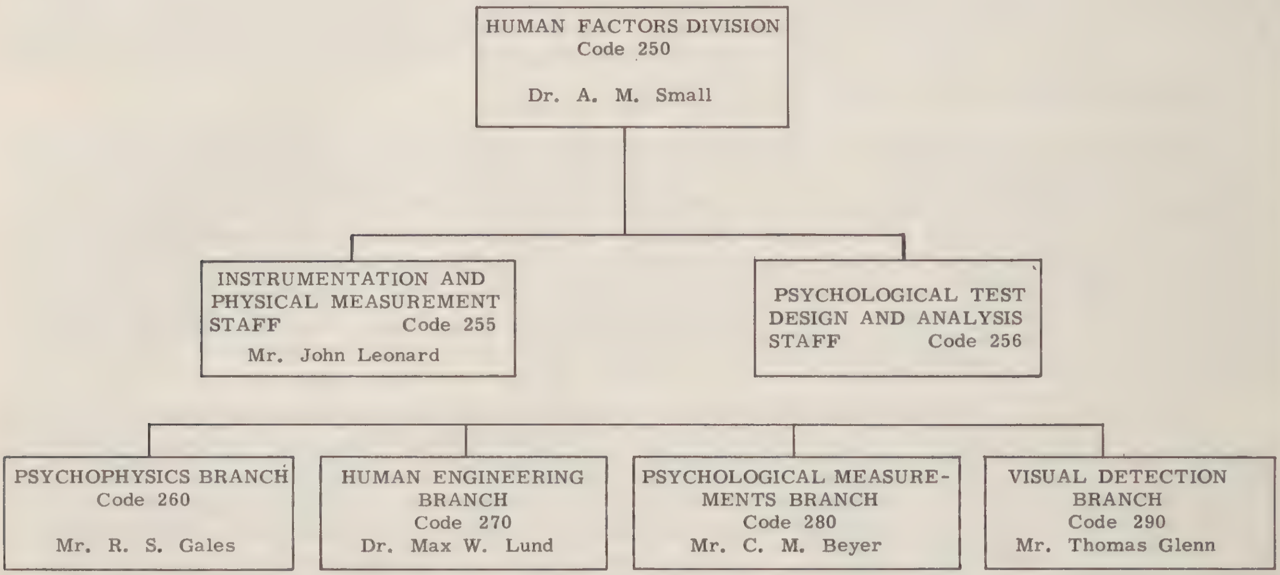
Dr. Lund: The afternoon's demonstrations will primarily tell our Human Engineering Branch story. However, I should like to add a word or two to that of Dr. Small's when he mentioned that the Human Factors Division assists the Bureau and its contractors in the human factors problems involved in electronic equipments, systems, etc. Now, we in the Human Engineering Branch are primarily responsible for the assistance that is provided to the Bureau engineers and contractors in terms of the design, the layout, the functional

requirements, etc., of pieces of equipment or of man-machine systems. Our job here is to tie the human operator into the equipment in such a way that you get away from the incompatibilities that Dr. Taylor talked about earlier, give him displays and controls which he can respond to with a minimum of computation and translation.

Again in line with what Dr. Small mentioned, we in the Human Engineering Branch spend quite a bit of time with our sister West Coast Navy Laboratories such as the Point Mugu Navy Missile Test Center, for instance, assisting them in the layout of such things as their launching and control areas and in study of tracking and record reading problems.

It will save time and help us in our schedule if you will read, before going on the tour, the dittoed sheet we passed out to you. You may wish to prepare questions in advance, so as to have them ready when you get into an area of interest to you.

Appendix



Organization Chart
U.S. Navy Electronics Laboratory
San Diego 52, California

HUMAN FACTORS DIVISION, Code 250

1. Conducts experimental and theoretical studies on human factors involved in the development, operation and use of electronic and electromechanical equipments and systems.

2. Makes engineering applications of research results through joint work with the Development Division and the Systems Division.

3. Furnishes consulting and engineering application services to the Bureau of Ships and to others as authorized by the Bureau of Ships.

INSTRUMENTATION AND PHYSICAL MEASUREMENT STAFF, Code 255

1. Devises, designs, assembles, maintains and calibrates a special instrumentation used for studies in the Division.

PSYCHOLOGICAL TEST DESIGN AND ANALYSIS STAFF, Code 256

1. Conducts surveys, makes analyses and assists in planning studies and applications of human factors research, especially from the point of view of closely related biological and mathematical sciences, for the improvement of man-machine performance.

2. Conducts studies in the design of experiments and in methods of data analysis.

PSYCHOPHYSICS BRANCH, Code 260

1. Conducts investigations on sensory-perceptual problems of signal detection, recognition and discrimination.

2. Studies methods of information presentation as related to human sensory-perceptual capacities.

3. Devises and evaluates specific signal portrayal techniques for use with electronic equipments.

4. Studies problems of speech communication with electronic systems.

HUMAN ENGINEERING BRANCH, Code 270

1. Applies human engineering principles to design of Navy electronic equipments and systems. Surveys research findings on human factors to determine their applicability to electronic design problems and to put them in digested form for engineers.

2. Conducts research on human engineering problems involved in electronic equipments and systems design, development, operation and use, including man as a component in information handling systems and as a control mechanism.

3. Studies and devises display techniques for coded information.

4. Studies environment as it influences the effectiveness of the man-machine combination and applies findings to the control of environment for optimum efficiency and reliability.

PSYCHOLOGICAL MEASUREMENTS BRANCH, Code 280

1. Conducts analyses of and studies on training equipments and systems.

2. Participates in the development of, evaluates training effectiveness of and writes instructor's manuals for electronic training devices.

3. Participates in the technical evaluation tests of Navy electronic equipments and systems.

4. Determines and measures the aptitudes and skills required to operate effectively electronic equipments and systems.

5. Develops materials for use with electronic training devices.

6. Assists Navy training establishments in the utilization of electronic training devices.

VISIBILITY AND CONCEALMENT EVALUATION BRANCH, Code 290

1. Conducts investigations to evaluate the effectiveness and suitability of concealment designs and measures for Navy vessels.

2. Participates in the theoretical studies and early developments of optical-electronic equipments in progress under Bureau of Ships contracts.

3. Develops and evaluates prototype equipments.

4. Furnishes consulting services to the Bureau of Ships and contractors.

DEMONSTRATION AREAS

1. Vorar (Visual order and reply)

H. O. Makinson
H. G. Gaylord

An analysis of the message requirements in the ASW System has resulted in a technique for visually presenting about 95% of messages. The visual display provides feedback, memory of the command or information, prompts the next step in a routine ASW attack and eliminates most of the confusion and voice message repeats of the old system. (Developed by NEL's Systems Division.)

2. ASTEC (Anti-Submarine Technical Evaluation Center)

W. H. Hockstra
C. C. Cram

This facility makes possible shore-based evaluations of equipments and man-machine combinations. It consists of (1) Madiddas and associated equipments for the generation of digital problem geometry and control of signal simulators; (2) A simulator area in which analogue problems are generated for driving scanning and searchlight sonars; (3) A main floor area where shipboard equipment and systems mockups are installed for evaluation and study.

3. Dark Room Facility

C. T. White

This facility provides space for study of the optical characteristics of filters and light sources applied to special area lighting problems. Selective Spectrum Lighting is demonstrated. Also, in this area, research on photic-driven EEG's is being conducted.

4. CRT Displays

J. W. Browder

A demonstration is given of the feasibility of using a projected dark trace tube and associated electroconductive glass for an automatic vertical summary plot. The memory of the dark trace tube may be controlled to give any amount of history required. A large diameter P19 CRT and a vidicon chain used in mine countermeasures research will be shown. H_2O/TV may be enhanced as a tool for classification of bottom mines by electronic gamma amplification.

5. Design Applications Facility

W. E. Woodson

A demonstration of techniques for panel and indicator lighting and materials used in applied human engineering. Commercially available hardware is utilized in these applications. Mockups of equipment and area layout are designed and constructed for study in this connection.

6. Target Classification Research

T. H. McGrath

The present study is an attempt to discover the discriminable stimulus characteristics which enable sonar operators to distinguish submarine for nonsubmarine aural and visual displays. The problem of classifying these two general displays in anti-submarine warfare has recently achieved great importance. The methodology of the present study is to investigate systematically the response characteristics of experienced operators as cues to train inexperienced operators.

7. Perceptual Numerosity Studies

P. G. Cheatham

Studies of the functional relationship between the perceived number and the objective number of light flashes, and of sound pulses, presented at rates of 10/sec. to 30/sec. The data support the hypothesis that perceived number in both vision and audition is determined primarily by a common time factor which is probably a cortical function.

8. Perceptual-Motor Facility

J. N. Stroud

D. R. Craig

This is a new facility. Unfortunately most of its components are "on order." However, the plans are available and some examples of the problems to be studied will be demonstrated. The general area of interest encompasses the operational description of the human component in man-machine systems. Research will be focused on determining the transfer characteristics available in the human component and the means by which these characteristics may be achieved. The task of the human component in each system will be studied at three levels: (1) the function of the human in the system, (2) the operations assigned for the accomplishment of that function, and (3) the discriminations and motor adjustments required in the operations.

NATURAL ILLUMINATION CHARTS

Dayton R. E. Brown
Navy Electronics Laboratory

We are sending to all members of the Vision Committee, and to others who may have use for them, a set of Natural Illumination Charts.

I want to introduce you to these charts and then speak briefly about another souvenir which we have for each of you.

It is the purpose of these charts to provide the Armed Forces with convenient and rapid access to the latest scientific information available on natural illumination. For clear days and clear moonless nights, the illumination in foot-candles falling on a fully exposed horizontal plane at any point on the earth, at any day of the year, and at any hour of the day or night, can be found quickly and simply. This information is of prime importance in answering questions relating to reconnaissance, visibility, concealment, and other naval and military problems. Because of the confidential nature of many of the problems, illustrations and examples of the use of this material are to be published under separate cover.

General distribution to naval and military personnel is being held up a bit longer for the examples.

Derivation of Basic Curve and Table. More than 12,000 measurements were made by the author in the Arctic, Anarctic, and the temperate and torrid zones of both hemispheres between January 1943 and May 1947. Photoelectric illuminometers manufactured by the General Electric Company were used for the measurement of light levels above one foot-candle. Lower levels were measured by means of a Luckiesh-Taylor Brightness Meter and a calibrated test plate. The illuminometers were calibrated by the U. S. Bureau of Standards before and after the measurements were made. The brightness photometers were calibrated by the Nela Park Laboratory of the General Electric Company.

The original data were plotted at large scale and a smooth curve was drawn. This basic curve was found to be in good agreement with fractional curves published in the scientific literature by Jones and Condit and others.

Plates 1 to 17, inclusive—Latitude Series. Each plate in this series applies to a given latitude as shown in the large figure at the top of the plate. Each plate contains a family of curves, each curve representing a given day of any year when the declination of the sun is as indicated on the curve. In this "Latitude Series" the illumination is plotted continuously as a function of time from midnight to noon and applies conversely from noon to midnight as indicated on the time scale. Plates were constructed after tabulating 33,500 solar altitude values and 33,500 corresponding values of the illumination.

Inspection of the latitude series clearly illustrates the sameness of the light at the equator day after day, throughout the year; sameness both as to time of occurrence and to range of intensity.

As one progresses away from the equator into the lower latitudes of the temperate zones, the most significant change from day to day is seen to be in the time of occurrence of the normal light distribution for that latitude. However, as one leaves the tropics a perceptible rise and fall in the moon intensity is found to occur from day to day. This becomes progressively more noticeable all the way to the Poles.

The rate of change from starlight to a dazzling light in the early morning at the equator is contrasted in this series with the very slow changes which occur in any one calendar day in the polar regions. Other characteristics of illumination peculiar to latitude can be noted; differences in the curves themselves. Also, you can pick off the times of sunrise and sunset and the altitude of the sun at other times of day and night for any place on earth.

Plates 18-43—Declination Series. Each pair of these charts is for a certain day of the year as indicated by the declination at the top of the page. The illumination is shown as a continuous function of latitude, each curve representing a given hour of the day. This series of curves, which derive from the same data previously described, is presented in this second form primarily to allow direct reading of illumination values at any latitude from one pole to the other for a series of days throughout the year.

Declination and Time. The approximate declination may be obtained from the graph here illustrated for a mean year (Figure 2). More accurate declinations are given in nautical almanacs.

The same holds true for the equation of time. All hours given are for Local Apparent Time, sometimes called True Sun Time. Conversion of clock or standard time to Local Apparent Time is explained in the text.

Clear vs. Cloudy Conditions. The charts and tables contained herein refer to light conditions during average clear days, clear days being defined as less than seven tenths overcast and with the sun's rays unobstructed to the locality in question. When the sun is obstructed by thin clouds, the values, regardless of the order of magnitude given, should be divided by two. For average cloud conditions obstructing the sun's rays, the values given for clear days should be divided by three. Occasionally, for dark stratus clouds preceding a heavy thunder storm, the values given can be divided by ten. However, this is not common.

Influence of the Moon. The illumination due to the moon may be estimated roughly from its altitude and phase as explained in the text.

I hope that these charts and tables may prove of value to oceanographers, meteorologists, photographers, agriculturalists, and other scientists as well as to naval and military personnel.

At the beginning of my remarks I mentioned military problems. In that connection I have one request to make. These charts cost Uncle Sam over $30,000 plus a lot of time and effort and I feel personally responsible to see that the services get the most they can out of them. Therefore, our request is that each of you send in examples telling us the use to which you have put this information so that we can pass these examples on to the services and to other scientists.

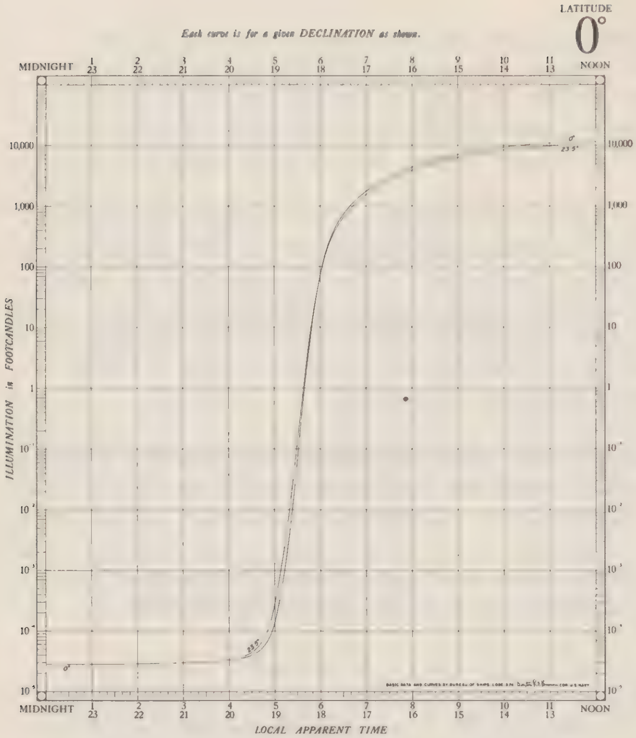


Figure 1

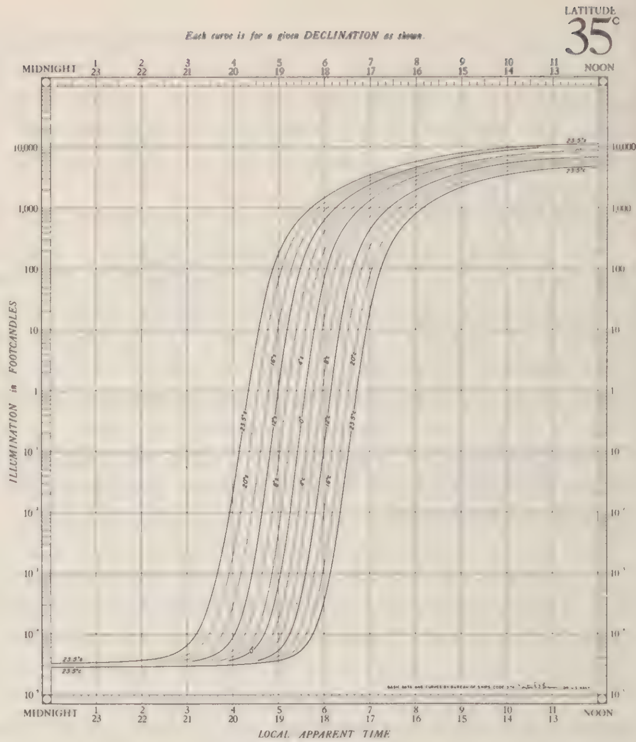


Figure 2

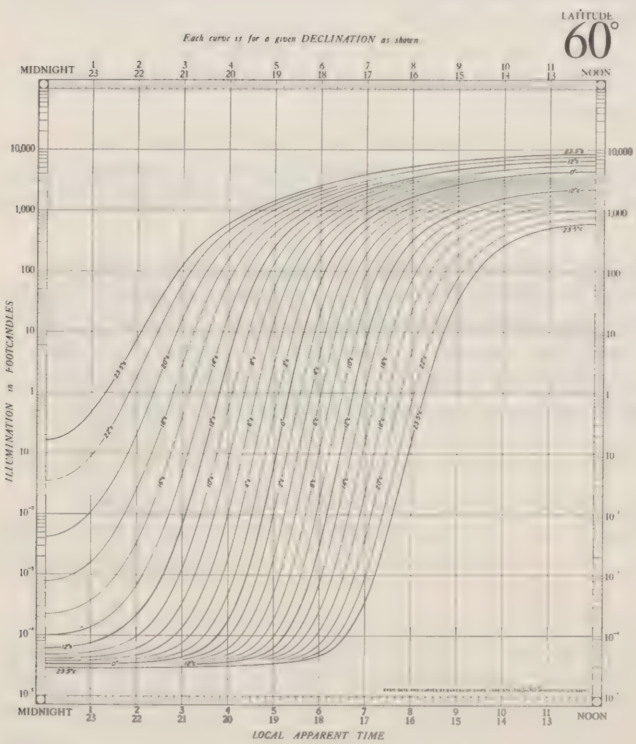


Figure 3

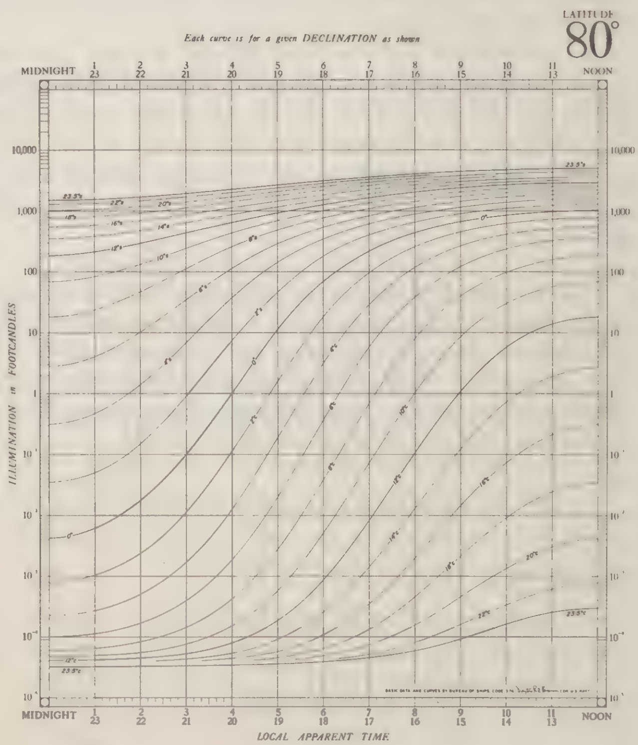
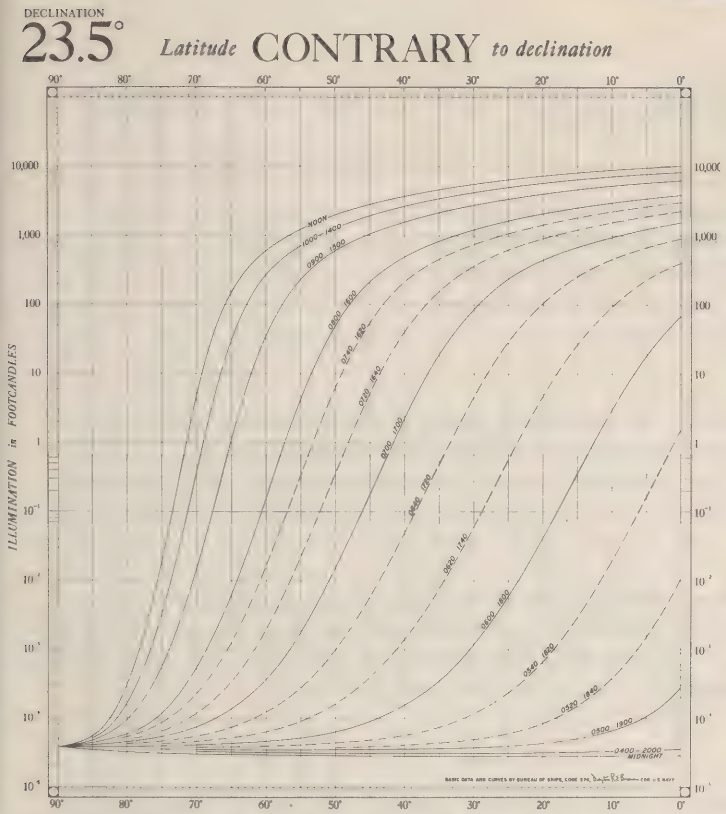
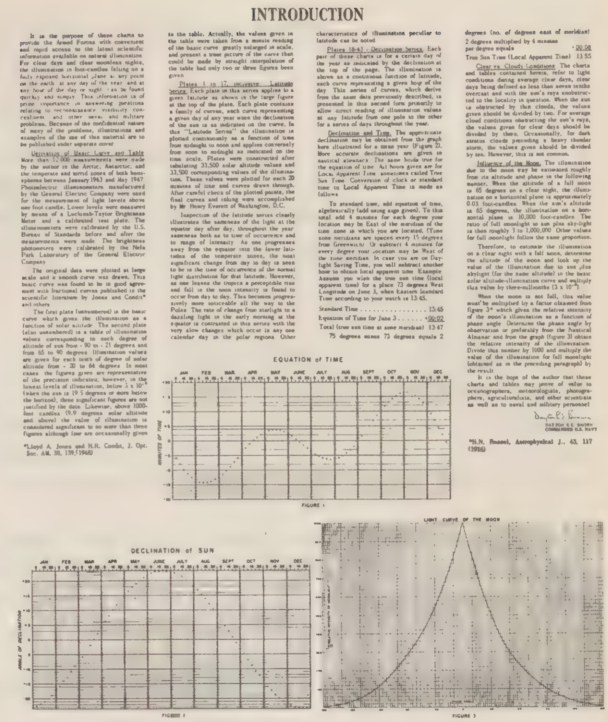


Figure 4



Each curve is for a given hour of LOCAL APPARENT TIME as shown.

Figure 5



INTRODUCTION

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The original data were plotted at large scale and a smooth curve was drawn. This basic curve was found to be in good agreement with fractional curves published in the scientific literature by Jones and Condit* and others.

The first plate (unnumbered) is the basic curve which gives the illumination as a function of solar altitude. The second plate (also unnumbered) is a table of illumination values corresponding to each degree of altitude of sun from - 90 to - 21 degrees and from 65 to 90 degrees. Illumination values are given for each tenth of degree of solar altitude from - 20 to 64 degrees. In most cases the figures given are representative of the precision indicated; however, in the lowest levels of illumination, below 5×10^{-5} (when the sun is 19.5 degrees or more below the horizon), three significant figures are not justified by the data. Likewise, above 1000-foot candles (9.9 degrees solar altitude and above) the value of illumination is considered significant to no more than three figures although four are occasionally given to the table. Actually, the values given in the table were taken from a minute reading of the basic curve greatly enlarged in scale, and present a truer picture of the curve than could be made by straight interpolation of the table had only two or three figures been given.

Plates 1 to 17, inclusive - Latitude Series. Each plate in this series applies to a given latitude as shown in the large figure at the top of the plate. Each plate contains a family of curves, each curve representing a given day of any year when the declination of the sun is as indicated on the curve. In this "Latitude Series" the illumination is plotted continuously as a function of time from midnight to noon and applies conversely from noon to midnight as indicated on the time scale. Plates were constructed after tabulating 33,500 solar altitude values and 33,500 corresponding values of the illumination. These values were plotted for each 20 minutes of time and curves drawn through. After careful check of the plotted points, the final curves and inking were accomplished by Mr. Henry Everett of Washington, D.C.

Inspection of the latitude series clearly illustrates the sameness of the light at the equator day after day, throughout the year: sameness both as to time of occurrence and to range of intensity. As one progresses away from the equator into the lower latitudes of the temperate zones, the most significant change from day to day is seen to be in the time of occurrence of the normal light distribution for that latitude. However, as one leaves the tropics a perceptible rise and fall in the noon intensity is found to occur from day to day. This becomes progressively more noticeable all the way to the Poles. The rate of change from starlight to a dazzling light in the early morning at the equator is contrasted in this series with the very slow changes which occur in any one calendar day in the polar regions. Other characteristics of illumination peculiar to latitude can be noted.

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Declination and Time. The approximate declination may be obtained from the graph here illustrated for a mean year (Figure 2). More accurate declinations are given in nautical almanacs. The same holds true for the equation of time. All hours given are for Local Apparent Time, sometimes called True Sun Time. Conversion of clock or standard time to Local Apparent Time is made as follows.

To standard time, add equation of time, algebraically (add using sign given). To this total add 4 minutes for each degree your location may be East of the meridian of the time zone in which you are located. (Time zone meridians are spaced every 15 degrees from Greenwich.) Or subtract 4 minutes for every degree your location may be West of the zone meridian. In case you are on Daylight Saving Time, you will subtract another hour to obtain local apparent time. Example: Assume you wish the true sun time (local apparent time) for a place 73 degrees West Longitude on June 3, when Eastern Standard Time according to your watch is 13:45.

Standard Time 13:45
Equation of Time for June 3 . . . . . . +00:02
Total (true sun time at zone meridian) 13:47

75 degrees minus 73 degrees equals 2 degrees (no. of degrees east of meridian) 2 degrees multiplied by 4 minutes per degree equals . . . . . . +00:08
True Sun Time (Local Apparent Time) 13:55

Clear vs. Cloudy Conditions. The charts and tables contained herein, refer to light conditions during average clear days, clear days being defined as less than seven tenths overcast and with the sun's rays unobstructed to the locality in question. When the sun is obstructed by thin clouds, the values given should be divided by two. For average cloud conditions obstructing the sun's rays, the values given should be divided by three. Occasionally, for dark storm clouds preceding a heavy thunder storm, the values given should be divided by ten. However, this is not common.

Influence of the Moon. The illumination due to the moon may be estimated roughly from its altitude and phase in the following manner. When the altitude of a full moon is 65 degrees on a clear night, the illumination on a horizontal plane is approximately 0.03 foot-candles. When the sun's altitude is 65 degrees, the illumination on a horizontal plane is 10,000 foot-candles. The ratio of full moonlight to sun plus sky-light is then roughly 1 to 1,000,000. Other values for full moonlight follow the same proportion.

Therefore, to estimate the illumination on a clear night with a full moon, determine the altitude of the moon and look up the value of the illumination due to sun plus skylight (for the same altitude) in the basic solar altitude-illumination curve and multiply this value by three-millionths (3×10^{-6}).

When the moon is not full, this value must be multiplied by a factor obtained from figure 3** which gives the relative intensity of the moon's illumination as a function of phase angle. Determine the phase angle by observation or preferably from the Nautical Almanac and from the graph (figure 3) obtain the relative intensity of the illumination. Divide this number by 1000 and multiply the value of the illumination for full moonlight (obtained as in the preceding paragraph) by the result.

It is the hope of the author that these charts and tables may prove of value to oceanographers, meteorologists, photographers, agriculturalists, and other scientists as well as to naval and military personnel.

DAYTON R.E. BROWN
COMMANDER U.S. NAVY

*Lloyd A. Jones and H.R. Condit, J. Opt. Soc. AM. 38, 139 (1948)

**H.N. Russell, Astrophysical J., 63, 117 (1926)

Figure 6

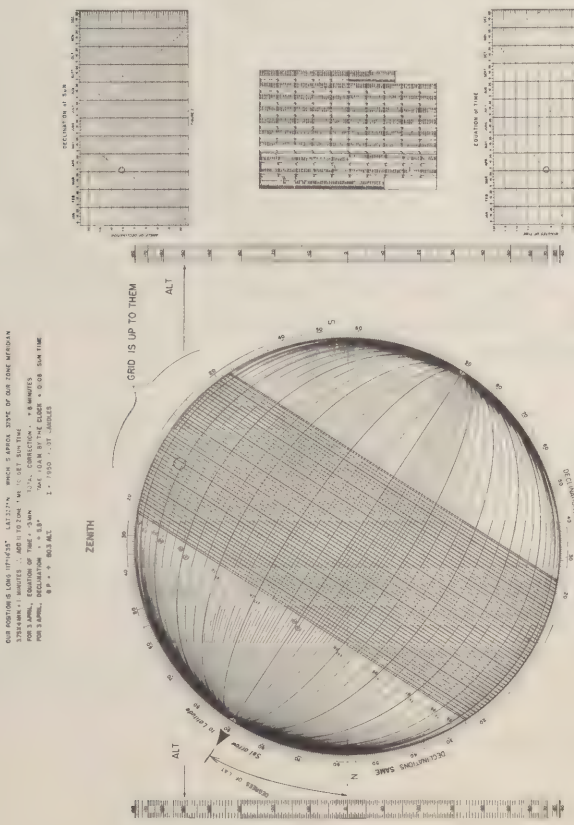

Figure 7

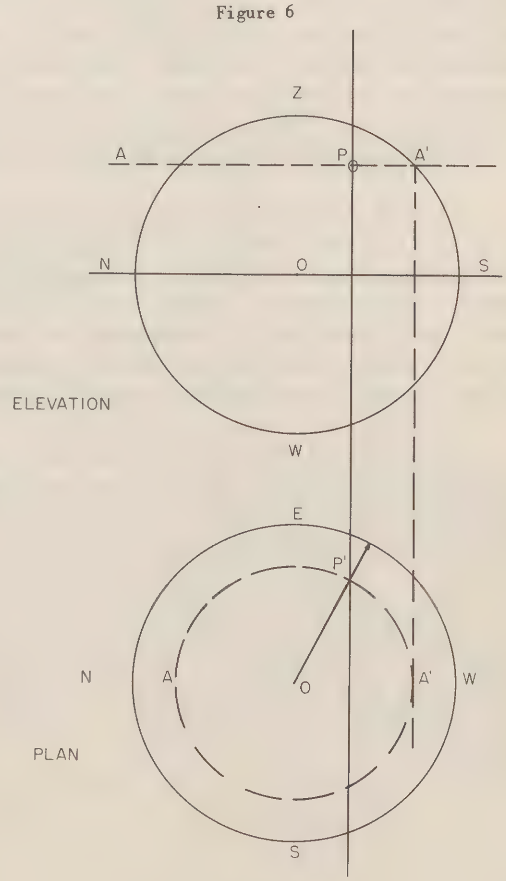

Figure 8

THE VERTICAL DISTRIBUTION OF MIE PARTICLES IN THE TROPOSPHERE

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1. INTRODUCTION

The Mie particles (those in the size range of 6×10^{-6} to 10^{-4} cm radius) cause many optical phenomena in the atmosphere and are especially responsible for variations of the atmosphere's optical properties. Their size distribution, chemical composition, and number density are fairly well known in the ground layer, but very little is known about these factors in the middle and upper troposphere.

The vertical distribution of Mie particles up to 4 km altitude has been discussed by Junge (1951); no data exist for higher layers. However, new information can be obtained from measurements of solar radiation carried out by Krug-Pielsticker (1949). We will evaluate these measurements and compare the results with other existing data.

2. MEASUREMENT OF SOLAR RADIATION

The measurements of solar radiation were carried out in an open airplane (Henschel Hs-126). In 1944, over Ainring, Germany, (ψ = 47 3/4°N, λ = 13°E, altitude 430m), eight successful ascents were conducted up to 9 km. Every 1000 m the ascent was interrupted, and the plane flew horizontally for 2 minutes to permit careful measurements. As the receiving instrument for solar radiation, a Linke-Feussner Panzeractinometer was used in connection with a Hartmann and Braun moving-coil galvanometer and a four-point recorder from Askania. Thus, the data were recorded and could easily be evaluated later, leaving the observer free to see that the instrument was pointed at the sun while recording.

It was of utmost importance to keep the temperature of the actinometer constant within ± 1°C. This was obtained by heating the tubes electrically, so that the temperature of instrument remained at 30 ± 1°C. A quartz filter was cemented on the top of the tubes (3 mm quartz, filter factor 1.095), and a red filter (Schott filter RG2, 1.5 mm, filter factor 1.14) would be slipped on to measure the intensity of the near infra red radiation. Calibration of the instrument was performed by comparison with a Compensation Pyrheliometer after Angstrom on the base station as well as on two summits in the Alps.

The total radiation through the quartz filter, as well as the infra red radiation through the quartz plus RG2 filter, was measured. This filter cuts off radiation below 6400 Å; therefore, the difference between the total and the infra red radiation corresponds roughly to the radiation in the visible spectrum.

The instrument, calibration and errors are described in detail by the author. The measurements are considered to be correct to ± 0.017 ly/min, and they are evaluated by the author to obtain turbidity factors, dust extinction and water vapor extinction values. All basic data are also tabulated. Since we are at present only interested in the attenuation by Mie particles, this attenuation is computed from the basic data in a different and improved way.

3. ATTENUATION COEFFICIENT OF MIE PARTICLES

3.1 Attenuation of Solar Radiation in the Atmosphere

The solar radiation is attenuated in the atmosphere by two components, namely by molecular scattering and by Mie scattering. The molecules scatter according to Rayleigh's law and, for this particular instrumental set-up, the coefficients to be used can be taken directly, as Krug did, from the attenuation coefficients for pure dry air given by Linke (1943). They change a little bit with air mass as a result of the shift of the optical center with air mass.

At the altitude h the solar radiation of intensity I_h is measured for a zenith distance of the sun ξ. The intensity of solar radiation below $\lambda = 6400$Å. outside the earth's atmosphere is $I_o = 0.777$ ly/min. The solar radiation is attenuated by molecules and Mie particles, the mass absorption coefficient being k, the density ρ and the path element ds. At the altitude h,

$$I_h = I_o \exp(-k_m \int_h^\infty \rho_m \, ds - k_p \int_h^\infty \rho_p \, ds) \quad (1)$$

where the index M refers to molecular scattering and P to Mie scattering. The first factor is the attenuation due to molecular scattering and the second factor is that due to Mie particle scattering; multiple scattering will be neglected.

We can simplify the first factor by introducing the scale height of the atmosphere, $H = \int_0^\infty (\rho_M/\rho_M)_o dh$, and the optical air mass,

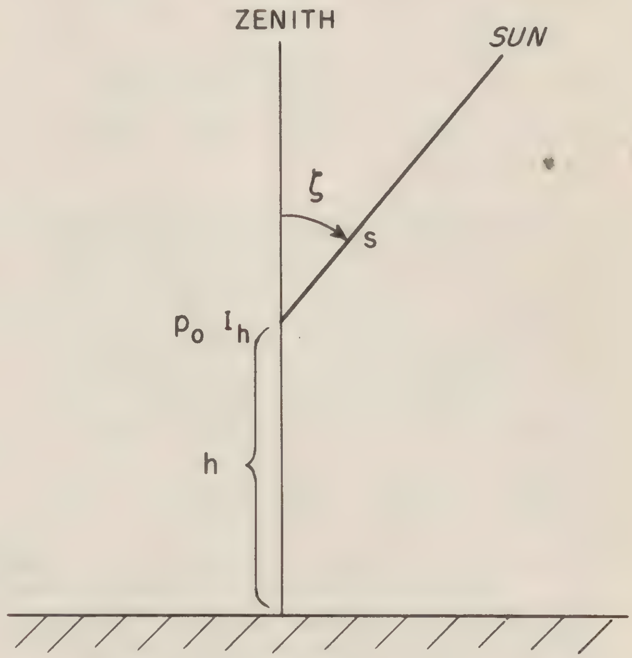

Figure 1

$M = p \sec \xi / p_o$, where p denotes the pressure (which is unity for a point on the surface of the earth and radiation coming in from the zenith). Thus

$$\int_h^\infty \rho_M \, ds = \rho_{M_o} \sec \xi \int_h^\infty \frac{\rho_M}{\rho_{M_o}} dh = \rho_{M_o} pH \sec \xi / p_o$$

or

$$\int_h^\infty \rho_M \, ds = \rho_{M_o} HM \quad (2)$$

Instead of the mass absorption coefficient k, the attenuation coefficient β per 1 km and a column of 1 cm^2 is used (dimension km^{-1})

$$\beta_M = k_M \rho_{M_o} \cdot 10^5 \quad (3)$$

Thus Eq. (1) becomes

$$I_h = I_o \exp(-\beta_M HM - k_p \int_h^\infty \rho_p \, ds) \quad (4)$$

3.2 Attenuation of Solar Radiation in an Atmospheric Layer

Now the attenuation of radiation is computed, whereby a change of zenith distance ξ between the two measurements is taken into account. Figure 2 shows the geometrical situation. From Eq. (1), the radiation received at altitude h_1 under zenith distance ξ_1, is given by

$$I_{h_1} = I'_{h_2} \exp(-k_M \int_{h_1}^{h_2} \rho_M \, ds - k_p \int_{h_1}^{h_2} \rho_p \, ds) \quad (5)$$

where I'_{h_2} means the radiation as received at h_2 under a zenith distance ξ_1 for $\int_{h_1}^{h_2} \rho_M \, ds$. We can write, according to Eq. (2), $\rho_{M_o} H(M_2 - M_1)$. Thus Eq. (5) becomes

$$I_{h_1} = I'_{h_2} \exp(-\beta_{M_o} H_M(M_2 - M_1) - k_p \int_{h_1}^{h_2} \rho_p \, ds). \quad (6)$$

We now turn our attention to the second factor in Eq. (6). We assume the concentration of Mie particles to be constant within a layer. This leads to

$$\int_{h_1}^{h_2} \rho_p \, ds = \rho_p (h_2 - h_1) \sec \xi_1.$$

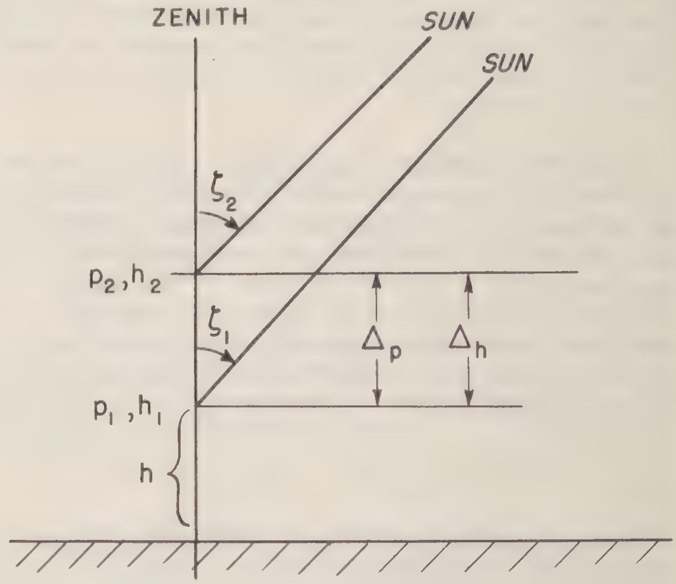

Figure 2

Since the layers are 1 km thick, this assumption is valid as a first approximation. Furthermore, instead of the mass attenuation coefficient we use $\beta_p = 10^5 \rho_p k_p$ as the attenuation coefficient per volume, namely of a cross section of 1 cm^2 and of a length of 1 km. Thus the dimension of β_p also becomes km^{-1}.

$$k_p \int_{h_1}^{h_2} \rho_p ds = \beta_p \sec \xi_1 (h_2 - h_1)$$

Now Eq. (6) can be written as

$$\ln(I'_{h_2}/I_{h_1}) = \sec \xi_1 \left\{ \beta_{M_o} H_M \frac{\Delta p}{p_o} + \beta_p \Delta h \right\} \quad (7)$$

in which β_{M_o} refers to ground value, but β_p is the actual attenuation coefficient within a layer.

At this time, we must take into consideration the fact that the radiation at h_2 was measured for a zenith distance ξ_2 and not ξ_1. From Eq. (4) it follows that

$$I_{h_2} = I_o \exp \left\{ - \sec \xi_2 \left[\beta_{M_o} H_M(p_2/p_o) + k_p \int_{h_2}^{\infty} \rho_p dh \right] \right\}$$

and

$$I'_{h_2} = I_o \exp \left\{ - \sec \xi_1 \left[\beta_{M_o} H_M(p_2/p_o) + k_p \int_{h_2}^{\infty} \rho_p dh \right] \right\}$$

In the last two equations the factors in brackets are identical, so we can write

$$I'_{h_2} = I_o \exp \left[- \frac{\sec \xi_1}{\sec \xi_2} \ln \left(\frac{I_o}{I_{h_2}} \right) \right] \quad (8)$$

We are now able to solve Eq. (6) by substituting I'_{h_2} from Eq. (8) into Eq. (6). With $(M_2 - M_1) = \sec \xi_1 \left(\frac{p_2 - p_1}{p_o}\right)$, we obtain

$$I_{h_1} = I_o \exp\left\{ - \Delta h \sec \xi_1 \left[\frac{1}{\Delta h \sec \xi_2} \ln\left(\frac{I_o}{I_{h_2}}\right) + \beta_{M_o} H_M \frac{\Delta p}{p_o \Delta h} + \beta_p \right]\right\}$$

Solving for β_p leads to

$$\beta_p = \frac{1}{\Delta h \sec \xi_1} \left\{ \ln(I_o/I_{h_1}) - \frac{\sec \xi_1}{\sec \xi_2} \ln(I_o/I_{h_2}) \right\} - \beta_{M_o} H_M \frac{\Delta p}{p_o \Delta h} . \tag{9}$$

4. NUMERICAL RESULTS AND THEIR DISCUSSION

Equation (9) contains only measured quantities, tabulated by Krug for eight flights. One assumption, however, has to be added, namely for the scale height H_M for each layer. Unfortunately, the temperature records are lost for those flights and I had to use the monthly temperature averages for those layers (Landolt-Boernstein 1952) to compute H_M. It is necessary to introduce this correction because H_M changes by about 15% from the lowest to the highest layer.

The error of the β_p is relatively large, if an observational error for I_h of ± 0.017 ly/min is allowed. Several checks showed that using the extreme values $I_h \pm 0.016$ ly/min leads to large deviations of β_p, thus only the order of magnitude can be regarded as established. However, it is hoped that the extreme deviations are not the rule and the errors cancel more or less for the mean values computed. To reduce the computational errors, four places were computed for each factor of Eq. (9).

It will be noticed that eight values between 3.5 and 6.5 km are negative. Such values have no physical meaning because β_p cannot become smaller than 0. First of all, the negative values are small (mean: $\beta_p = -0.0026$ (km^{-1})) and they fall definitely within our limits of accuracy. Therefore, two types of mean values are computed: M_1 is the arithmetic mean of all values, M_2 the arithmetic mean of all positive β_p, assuming $\beta_p = 0$ for all negative values. The differences between M_1 and M_2 are actually insignificant.

The negative values can be explained, besides being within normal limits of accuracy, as due to irregular distribution of Mie particles in the atmosphere. The atmosphere is not at rest and if these particles are suspended in a cloud-like form in the atmosphere, measurements must lead to negative values of β_p. Measurements at two levels, h_1 and h_2, are carried out 5 to 10 minutes apart. Figure 2 illustrates this situation. While carrying out measurements at h_2, a cloud of particles moved into the light path; thus, I_2 is much smaller than I'_2. This leads to a large value of the ratio I_o/I_2, hence to a smaller difference of the two factors in Eq. (9). It must also be remembered that by using an ascending airplane the light path through the atmosphere was different for each altitude.

The individual data obtained are tabulated together with the mean values. If the mean values are plotted on a semilogarithmic paper (Fig. 3), it is quite striking that up to 4.5 km the attenuation coefficient falls off exponentially,

$$\beta_p(h) = \beta_{p_o} \exp(-h/H_p), \tag{10}$$

where $\beta_{p_o} = 0.590$ (km^{-1}), $H_p = 0.98$ km and h is the altitude in km. Above 4.5 km the values of β_p are practically constant with altitude. They follow a law

$$\beta_p(h) = \beta_p' \exp\left\{(h - 4.5)/H_p'\right\} \qquad (11)$$

with $\beta_p' = 0.006$ (km^{-1}) and $H_p' = 22$ km. However, in this case, the factor $H_p = 22$ is not very well established.

There seems no doubt, however, that the distribution changes abruptly at about 4.5 km. We shall discuss this fact in more detail in Chapter 7.

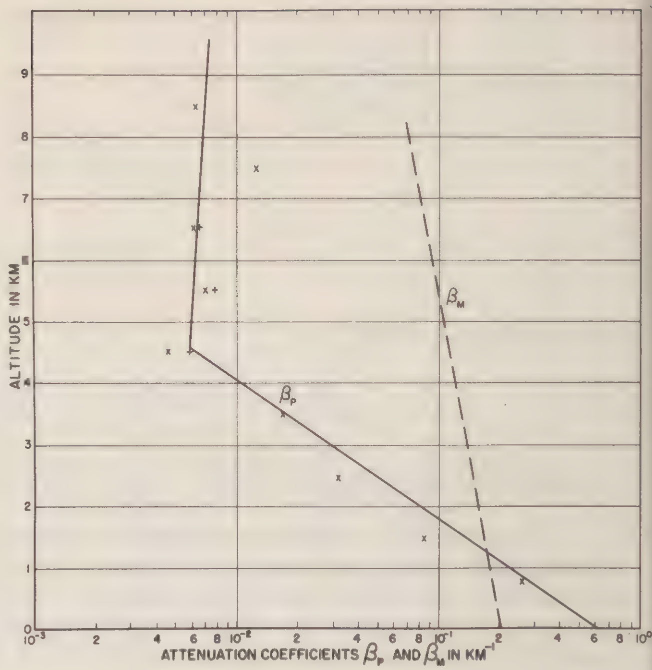

Figure 3

5. COMPARISON WITH KRUG'S RESULTS

Krug computed β_p differently. She computed the attenuation above each layer, namely the factor $k_p \int_h^\infty \rho_p \, dh$ of Eq. (11) and derived the values of β_p as differences $k_p \int_{h_1}^\infty \rho_p \, dh - k_p \int_{h_2}^\infty \rho_p \, dh$. If this procedure is written in our notation we obtain, similarly, Eq. (9). However, the correction of H_M has not been applied and, also, some other errors must have occurred, because some of Krug's values are quite different from ours. In general, her values are 10-20% lower than ours. Also, Krug did not notice the height variation of β_p as given in Eqs. (10) and (11).

Our new calculation was essential to get correct results.

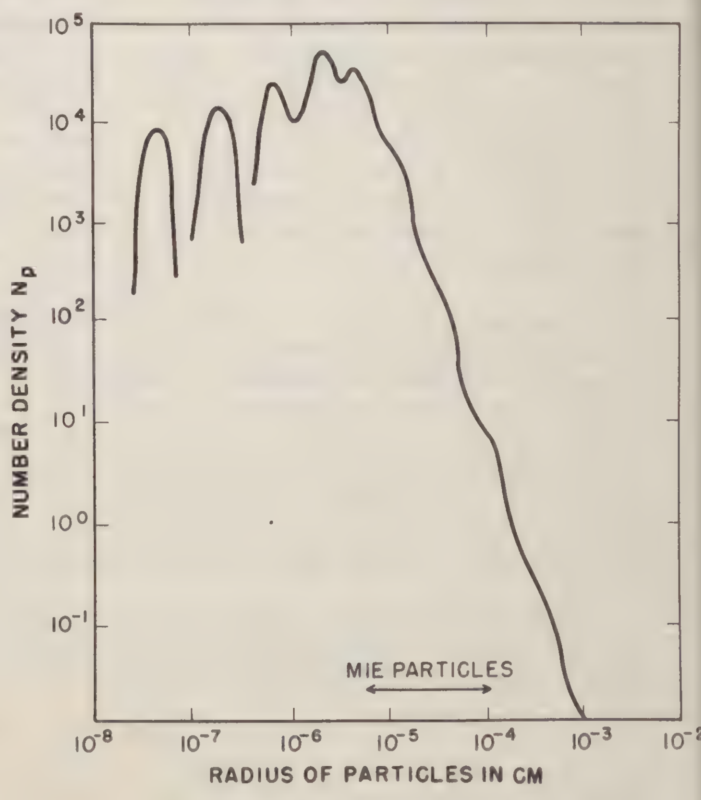

Figure 4

6. THE SIZE DISTRIBUTION OF THE MIE PARTICLES

The size distribution has been measured in the ground layer only. The most startling result has been obtained and confirmed by Junge (1952) and is reproduced in Fig. 4. For the size range of Mie particles we can write for the number of particles dN per radius range dr

$$\frac{dN_p}{d \log r} = \text{const} \times r^{-3} \qquad (12)$$

or

$$dN_p = \text{const} \times \log e \times r^{-4} dr$$

This means the number of particles for unit value dr falls off with increasing r. This r^{-3} law seems to hold pretty well for measurements in various places as long as no fog occurs. It is established in the ground layer and also on top of a mountain at about 10,000 feet altitude.

As a first approximation, we may say it holds in the troposphere. However, actual measurements are planned to find out what this size distribution looks like in the upper troposphere.

The attenuation coefficient β_p, used before, is

$$\beta_p = 10^5 \int_{r_o}^{r_1} \sigma(r)\, dN_p \tag{13}$$

with σ = attenuation cross-section per particle (cm^2) and dN_p as defined before. The value of σ depends very strongly on the radius of the particles, according to

$$\sigma(r) = \pi r^2 K(\alpha, m), \tag{14}$$

where $K(\alpha, m)$ is the efficiency factor determined by the Mie theory. To derive the effective attenuation cross-section for a range of sizes and a wide wavelength region is more complicated, and we shall not deal with this problem here. However, from Eq. (13) it can be seen that for a size law operating throughout the troposphere the value is directly proportional to a number density N_p. Thus, our values are a clear indication of the number of Mie particles in each layer.

7. RESULTS OF OTHER INVESTIGATIONS

In the last section, it was shown that the computed β_p values are proportional to the effective number of N_p. Thus, our Fig. 4 shows the vertical distribution of N_p. Fortunately, there exist other measurements which can be compared with our results; the data are taken from a survey by Junge (1951). Shown in Fig. 5 are those which correspond to fair summer weather situations, which means we exclude those with a strong temperature inversion on top of the ground layer, ground fog or strong ground haze.

The curves are not copied from Junge, but drawn after the original data. A comparison of his Figs. 2 and 3 and our Fig. 5 shows the possible interpretation of the original data, but these differences are minor. Since various methods have been employed, the actual values cannot be compared. For that reason, the ground value is always assumed equal to 1. Such a representation best shows the decrease with altitude.

Curve a is based on measurements of condensation nuclei and solid particles from twenty-eight balloon flights over Central Europe. The values can be best interpreted by a steep exponential decrease up to 2.1 km and a less steep one above that altitude up to 5.5 km. Curves b and c are based on measurements of solid particles with the konimeter installed in an aircraft. They were carried out by Siedentopf over Germany. Curve b is based on twelve flights in summer, c on eight flights in winter.

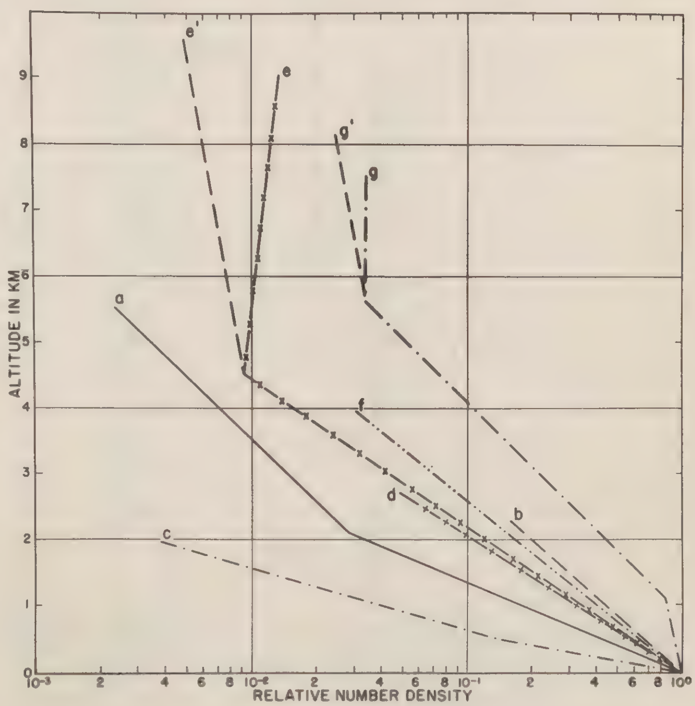

Figure 5

TABLE 1

Attenuation Coefficients for Mie Particles: β_p measured with an Actinometer in the Region Below 6400Å

(based on measurements carried out by Krug in 1944)

Mean altitude (m)	11 Apr	18 Apr	9 May	28 June	30 Sept	13 Oct	24 Oct	26 Oct	M_1 Mean Values	M_2 Mean values if for negative β_p; β_p = 0 is assumed
785			(0.186)		(0.213)	0.199	0.263	0.426	0.258	0.258
1500		0.054	0.186		0.213	0.017	0.014	0.017	0.084	0.084
2500		0.039	0.074		0.015	0.017	0.018	0.022	0.031	0.031
3500	0.033	0.027	0.016		0.028	-0.002	0.011	0.003	0.016	0.017
4500	-0.009	0.013	0.015		0.006	-0.002	0.008	-0.000	0.004	0.006
5500	0.008	-0.001	0.008	0.024	-0.003	0.007	0.014	-0.002	0.007	0.008
6500	-0.000	0.000	0.008	0.021	0.009	0.007	-0.001		0.006	0.007
7500		0.003	0.008	0.018	0.024				0.013	0.013
8500			0.006						0.006	0.006

Unfortunately, they cover only the lowest 2 km. The summer curve fits closely to the other data, whereas the winter curve shows a very steep decrease with altitude, indicating a large amount of dust accumulating near the ground. Since this is the only winter measurement, it cannot be compared with the other curves.

Rossmann's data, obtained from eighteen flights, are shown in curve d. These data are obtained by the same method as that of Siedentopf, and the results very closely resemble his. Curve f is based on an indirect method. The data are obtained from measurements of the potential gradient by means of twenty-two sailplane flights over the same area employed by Krug. The data are taken during anticyclonic weather situations, with dust well above 4 km and only a few scattered cumulus clouds.

Curve g is obtained from measurements of zenith sky brightness carried out by Siedentopf during eighteen flights over this same area. These data show a shallow ground layer, with little change of the particle concentration up to 1.2 km. From this height the particles decrease exponentially up to 5.5 km. Above this altitude, no appreciable change is likely to occur.

A comparison of all five curves (excluding curve c) with our computations shows that they agree in a general fashion. The number of particles decreases exponentially up to 4 or 5 km. Above that altitude, the number density remains more or less constant. The vertical distribution of particles below 4-5 km can be expressed as

$$N(h) = N_o \exp(-h/H_p).$$

Values of H_p are computed in Table 2, and a mean value, $H_p = 1.2$ km, is obtained.

TABLE 2

Values of the Constant H_p for the Various Measurements of Particles

Curve (Type of measurement)	Altitude range (km)	H_p (km)
a (condensation nuclei	0-2.1	0.59
and solid particles)	2.1-3.5	1.38
b (solid particles)	0-2.2	1.28
c (solid particles)	0-2.0	(0.41)
d (solid particles)	0-2.75	0.91
e (solar radiation)	0-4.5	0.98
f (potential gradient)	0-4.0	1.16
g (zenith sky luminance)	1.2-5.7	1.41
	Mean	1.2

In meteorology, the mixing ratio is used to show whether an atmosphere is thoroughly mixed or not. In a well-mixed atmosphere the mixing ratio for Mie particles should remain constant with altitude. Following the general definition for the mixing ratio,

$$q = \frac{\rho_p}{\rho} \cdot 10^{-6} = 10^{-6} \frac{N_p m_p}{Nm} \left(\frac{\text{g particles}}{\text{kg dry air}}\right).$$

The height variation of q is given by

$$q(h) = 10^{-6} \frac{m_p}{m} \left(\frac{N_p}{N}\right)_o \left\{ e^{-h/1.2} / e^{-h/8} \right\}$$

if Eq. (10) and H = 8 km for dry air are used. This leads to

$$q(h) = \text{const } e^{-0.708h} . \tag{15}$$

This decreasing mixing ratio indicates a source on the ground.

Above 5 km, however, the mixing ratio increases with height. If Eq. (11) is used,

$$q(h) = \text{const x } e^{(h-5)/H_M} . \tag{16}$$

We would expect a thoroughly mixed atmosphere that meant

$$q(h) = \text{const} \tag{17}$$

or, in other words, $H_p = H_m$. A β_p for q(h) = const has also been drawn for curves e and g through the points at 4.5 and 5.5 km, respectively. A curve with an increasing q(h) indicates a source region, for instance at the tropopause or higher. Falling meteor dust particles would lead to a mixing ratio given by Eq. (16). The whole curve may also mean a change in the size distribution function. Therefore, too optimistic speculations should not be drawn.

The decrease of Mie particles in the lower 4-5 km agrees with Junge's (1951) austausch consideration, in which he showed that the dust cap over Central Europe, where these measurements are largely derived, should be approximately 4 km.

8. INDICATIONS OF LARGE CONCENTRATIONS OF MIE PARTICLES IN THE UPPER TROPOSPHERE

The measurements discussed in the last section indicate a relatively large concentration of Mie particles in the upper troposphere, namely between 5 and 11 km. But this fact is supported by visual observations. Siedentopf (1944) states in connection with his measurements mentioned in the last section: "Frequently haze can be found up to the tropopause." Packer and Lock (1950) say: "Presumably then, the atmosphere even above 38,000 feet contains foreign particles of dimensions small with respect to wavelength, in addition to air molecules." The large deviation of the scattering functions they obtained, from Rayleigh's function, shows that Mie particles must be present throughout the whole troposphere. Furthermore, the fact that cirrus clouds occur in the upper atmosphere proves that a large amount of nuclei and therefore particles in the size range of Mie particles must be present.

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Discussion:

Dr. Duntley commented that Dr. Penndorf had sent him an advance copy of a report covering some of the material in his presentation and some additional material on slant path visibility. Although Dr. Duntley had not yet been able to give the report a really careful reading, he offered compliments to Dr. Penndorf on the work he had done and expressed regret that there had not been sufficient time for a presentation of the entire work. Dr. Duntley said that the subject of slant range visibility had been a long-term interest of his; he found, however, that Dr. Penndorf's approach for calculating the attenuation coefficient within the atmosphere to be new and valuable and one which ties in nicely with other approaches. It derives its basic nature from different data from those used by others, data which are also different from those Dr. Duntley and his staff plan to use in their forthcoming experiments. Dr. Duntley concluded with further praise of the extremely valuable work being done at the Air Force Cambridge Research Center.

DAY SKY BRIGHTNESS MEASURED BY ROCKETBORNE PHOTOELECTRIC PHOTOMETERS*

H. A. Miley, ** E. H. Cullington, J. F. Bedinger

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Air Force Cambridge Research Center
Cambridge, Massachusetts

Several experiments have been conducted since 1946 to measure skylight in the upper atmosphere. From the results it appears that sky brightness measurements consist of (1) sunlight scattered by the atmosphere (particularly important in the lower atmosphere), and (2) day airglow (light originating in the upper air by other means than Rayleigh scattering). The scattered light values are large at the ground but decrease rapidly (almost proportional to atmospheric density) until at about 30 kms. the sky is relatively black, the measurements being about 2 to 3 percent (depending on direction) of those recorded at the ground-level. The scattered light becomes unimportant in comparison with airglow at about 35 to 40 kms. Day airglow appears to be nearly constant in the range 40 to 130 kms. and is much larger than predicted by existing theories. Photometers employing interference filters gave day airglow values which are of the order of ten thousand times the corresponding night airglow values. Evidence of large light values at high altitudes is given by photographs of clouds made at an altitude of 70 kms. Preliminary measurements indicate a diurnal variation in intensity of the airglow.

Introduction

The night sky radiations have been the subject of many research papers, but relatively little has been known about the day sky. The variability of the scattering qualities of the near-the-ground layer of the atmosphere must have discouraged the study of scattered light in this region. The large amount of scattered light (daylight) has prevented daytime investigations of light emitted in the upper atmosphere. The advent of rockets, plastic balloons and greatly improved measuring techniques make it possible to explore the scattered light and day airglow (light originating in the upper atmosphere by other means than Rayleigh scattering) at various altitudes within the vertical range of the vehicles. The objective of the experiments being reported was to measure skylight at selected wavelengths by means of rocketborne photoelectric photometers. Stated otherwise, what a photometer (as nearly monochromatic as possible) may "see" in the range ground-level to the top of the rocket's trajectory was to have been recorded.

Numerous studies have been made by weather bureaus and other agencies of total or partial radiation from (1) the sun, (2) the sky, and (3) from the sun and sky as measured by earthbound equipment. Pyrheliometers and photometers (using thermocouples, thermopiles, bolometers, or phototubes as radiation detectors) have furnished the bases of most of these methods. Some of these equipments have been used for studying night sky brightness and some for measuring day sky brightness. A few measurements have been made above the earth's surface by airplane or balloon-borne equipment. Since these experiments have been concerned only indirectly with skylight, they will not be reviewed at this time.

Rockets impose certain difficult requirements in these experiments. The equipment should (1) be of light weight and small in volume, (2) provide pressurized containers for the higher voltage portions, (3) possess self-contained power supplies and respond automatically and instantaneously, (4) be adjustable to a wide range of light intensity values, (5) possess

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* A more complete description is to appear soon in the Proceedings of the Geophysical Union.
** Now at Wright Air Development Center, Dayton, Ohio.

durable qualities (meaning that it must pass rigid shake and shock tests), (6) maintain constancy of calibration, or have a means of calibrating it during the flight, (7) provide a D. C. voltage signal output always in the range acceptable to telemetering and proportional to the light intensity being measured, (8) be able to supply the output signals to a high impedance telemetering system, from which they are sent to ground recorders, and (9) be adjustable to a limited number of telemetering channels and to the remote controls for putting on and off the various power supplies before the rocket is launched. There is also the need of a means of tracking the rocket, determining its aspect, and avoiding unwanted radiations from the sun and from other directions.

A. V-2 Rocket Flight, 31 August 1950

As was verified in earlier experiments, the V-2 rocket maintains nearly a constant azimuth orientation before fuel cut-off and usually rolls slowly after cut-off. It was desirable, therefore, to design photometers so as to eliminate a large portion of the roll effect. The main purpose of the experiments in 1950 and 1951 was to measure skylight at altitudes greater than 30 kilometers.

The results of the previous experiments dictated several important changes. (1) Greater sensitivity was provided by using multiplier (1P21) phototubes. (2) This made it possible to reduce the viewing cone's radial angle to about 5. 5 degrees. (3) Photometer appendages were designed to reduce the roll effects of the rocket. Other experiments in this rocket required that these skylight measurements be made without the use of any rotating parts such as commutators used previously for varying the sensitivity range.

The simplicity of the optional system may be seen from Figure 1 which merely represents the principles involved in these and subsequent experiments designed for rocket flight conditions.

The response curves of the interference filters, as recorded

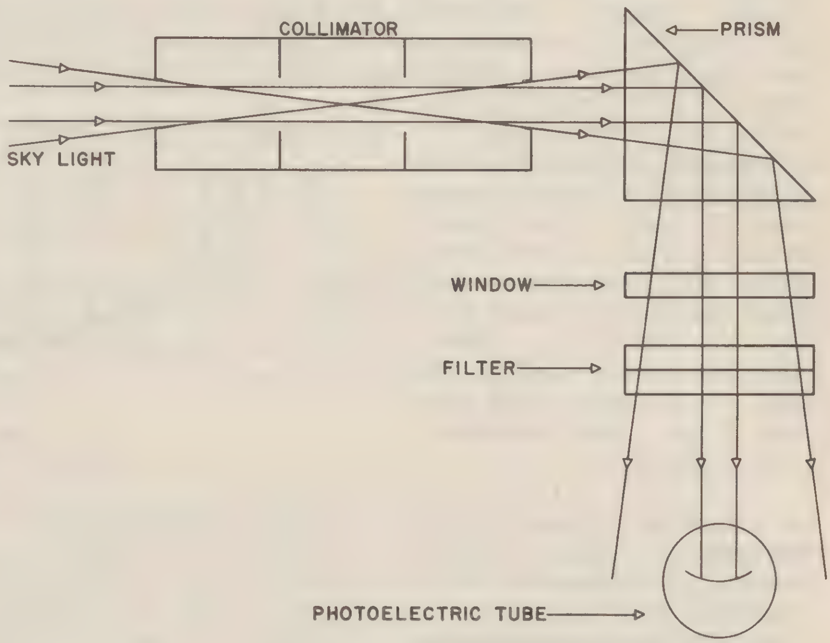

Figure 1

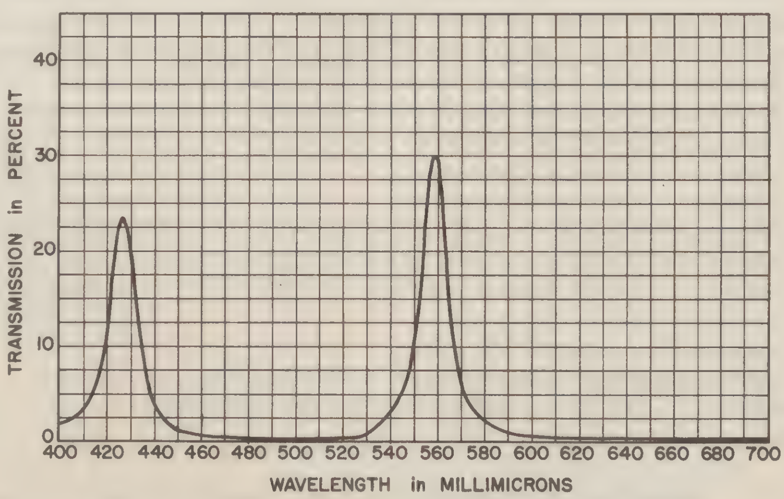

Figure 2

by the Hardy spectrophotometer (at MIT) are shown in Figure 2. The 4260 Å filter was chosen because it is generally considered that there is a N_2^+ emission band at 4278 Å in the night airglow and auroral spectra. The 5590 Å filter was selected because of the presence of an oxygen line at 5577 Å in night, twilight and auroral spectra.

The rocket reached an altitude of approximately 135 km. and precessed so much that it was flying "backwards" at the peak of the trajectory. Since a commutator was not used, the photometers provided continuous records. Figures 3 and 4 give representative values read from these recordings. Figure 3 shows that light intensity decreases rapidly, and nearly exponentially from ground-level to an altitude of about 35 kms. From these results it appears that most of the light measured in this range may be attributed to Rayleigh scattering. The measurements of light at 30 kms. were about 1 to 2 percent of the values recorded at ground-level.

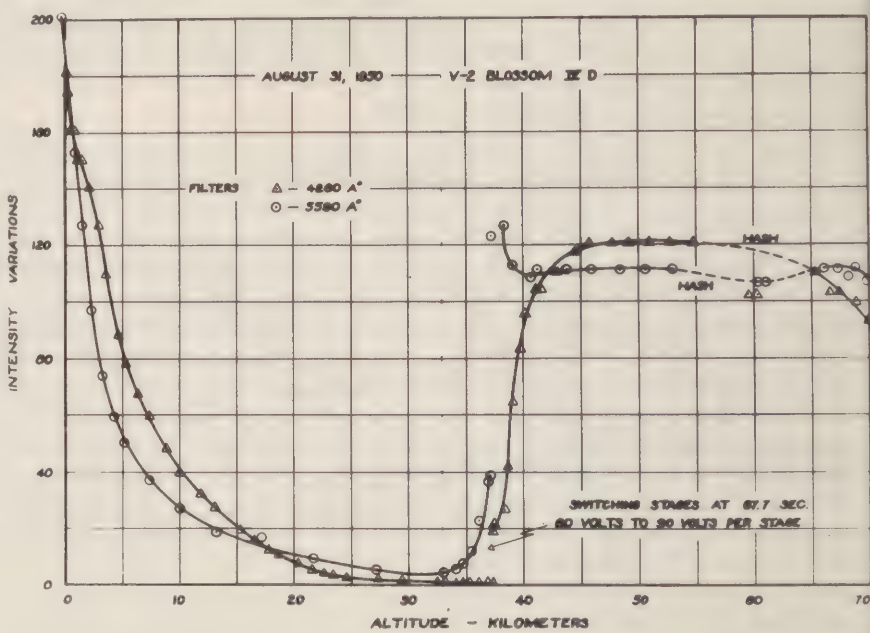

Figure 3

For the remainder of the flight the values of light are largely independent of altitude. Both the constancy and large order of magnitude of the readings were astonishing. Obviously, Rayleigh scattering cannot account for these results. The light values began increasing after fuel cut-off at 67 seconds, and amplification of about 25 was provided by changing the stage voltages. The combination of these two effects produced excessively large readings in the range about 40 to 70 kms. As readings of this magnitude were not anticipated, calibrations for this sensitivity range were not available.

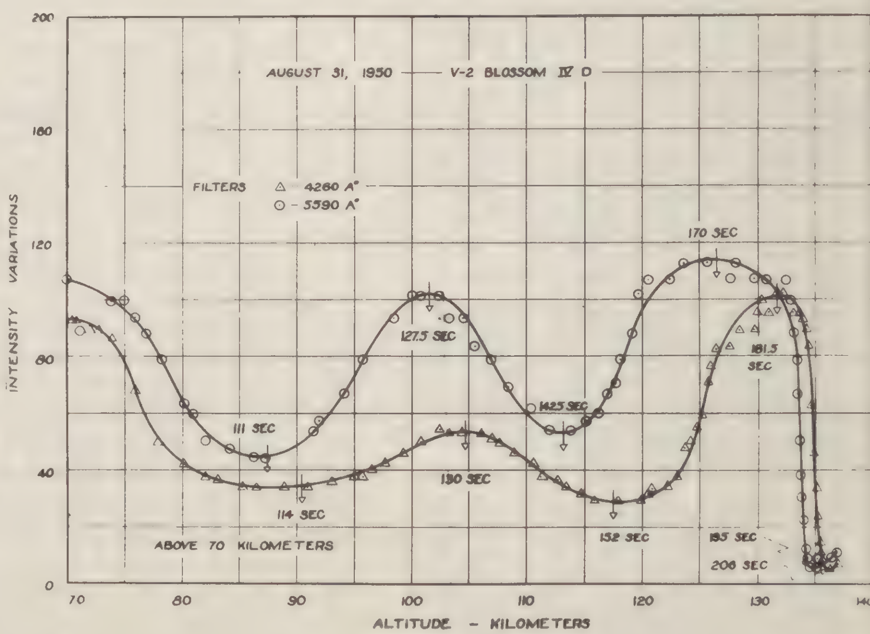

Figure 4

The cyclical nature of the data may be connected with the rotation of the rocket. The tracking telescopes gave a roll period of 60 seconds from the time of fuel cut-off to 70 kms.;

no roll information was obtained after 70 kms. A large object was ejected from the rocket at an altitude of about 70 kms. which may have altered the rotation period. In these cyclical effects are included intensity changes due to (1) the rotation of the photometer appendages alternately through the sunny and shaded areas of the rocket, (2) the precession of the rocket, and (3) variations in skylight with directions.

Taking the minimum values in the neighborhood of 85 and 115 kms. as representing the amount of light at these altitudes and in the direction of the photometers, the comparisons shown in Table 1 are obtained.

Table 1

COMPARISON OF THE INTENSITIES OF LIGHT IN MICROWATTS PER SQUARE METER OF 20A BAND WIDTHS RECEIVED FROM A HEMISPHERE*

Filters	30 kms.	85 kms.	115 kms.
4260 A	10×10^3	6.0×10^3	5.2×10^3
5590 A	12×10^3	5.5×10^3	6.6×10^3

*This represents the 20 A band of energy received by a flat surface of one square meter from a hemisphere of diffuse scattering equal to the average of that measured by the recessed phototube.

B. Aerobee Rocket Flight, 25 July 1951

Equipment was designed to the specifications of an Aerobee rocket for measuring day airglow in the upper atmosphere. The tip of the rocket's nose cone was jettisoned at about 35 kms. admitting light through a series of eight interference filters mounted on a single rotation disk. Two independent columns of light, each about one-fourth inch in diameter, were admitted to openings on opposite sides of the disk. These columns were admitted from the direction of the longitudinal axis of the rocket. In this way independent spectral series of light values were presented to be recorded each half second (the rotation period of the disk). The two recording photometers were operated at different sensitivity ranges and each served as a calibration check on the other. The ninth opening in the rotating disk contained a grain-of-wheat light, operated on constant voltage, to provide a calibration service during the flight. The conical viewing angles' radius was about 4 degrees. The filters were "peaked" at most of the well-known lines and bands in the visible range, and some were selected for measuring the energy in the spectral airglow "windows"; the energy at various wavelengths should be measured.

The phototube outputs for the set of eight filters varied greatly due to differences in (1) phototube spectral sensitivity, (2) filter transmissions and (3) the expected spectral distribution of day airglow. An attempt was made through the use of neutral filters to bring all the responses within the sensitivity range.

The readings showed that the intensity of light recorded was somewhat greater than that measured in 1950 and that the filter combinations in the range 4200 A to 5900 A transmitted more light than could be recorded. Readings from three filters were within the acceptable sensitivity range and are given in Figure 5. These results show that the large and constant amount of light measured in 1950 has been verified at other wavelengths. The constant values measured at these three wavelengths are given in Table 2. From the known

sensitivity limit of the equipment, the light intensity for the respective regions of the other five filters can be shown to be greater than the values given in column 3 of Table 2.

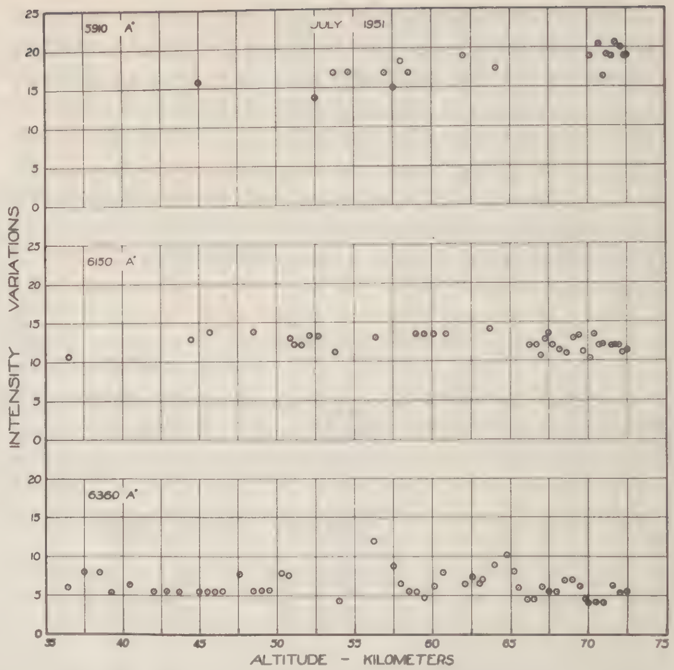

Figure 5

The magnitude of the light values obtained in 1950 suggested that a sensitive camera should be carried in the 1951 flight. Accordingly, a camera was mounted in the rocket so that it was "looking" in the same direction as the photometers. Representative photographs of clouds taken at an altitude of about 70 kms. are shown in Figure 6. These three photographs were taken from successive frames of 16 mm film and show clearly the rotation of the rocket. It is believed that these clouds are above an altitude of 70 kms. because (1) no evidence of rocket instability has been obtained (aspect data obtained to an altitude of 55 kms. showed the rocket to be flying very stably), (2) of the apparent nearness of the clouds to the camera (lower atmospheric clouds photographed from such an altitude are different in size and sharpness of focus), and (3) the photometer values, Figure 5, obtained while the rocket was known to be stable (from aspect data) did not change; these photometers did record saturated values after parachute ejection when they were expected to "look" earthward.

Table 2

COMPARISON OF THE INTENSITIES OF LIGHT IN MICROWATTS PER SQUARE METER FOR 20 A BAND WIDTHS RECEIVED FROM A HEMISPHERE

Filters	Average value 30 to 70 kms.	Values 30 to 70 kms. are greater than	Ground value at flight time
6360	6.9×10^3		2.3×10^5
6150	6.0		2.5
5910	3.3		1.5
5590		20×10^3	8.3
5390		11	2.3
4895		19	6.3
4615		14	5.0
4290		9	3.3

The nature and exact location of these clouds are to be determined. From the photographs they appear near enough to be in the cold layer at about 80 kms.

Figure 6 (1)

Figure 6 (2)

Figure 6(3)

General Discussion

From the results presented above one may visualize what a monochromatic photometer, with fixed orientation, may "see" in traversing the earth's atmosphere. Figure 7 presents the authors' version of this light distribution.

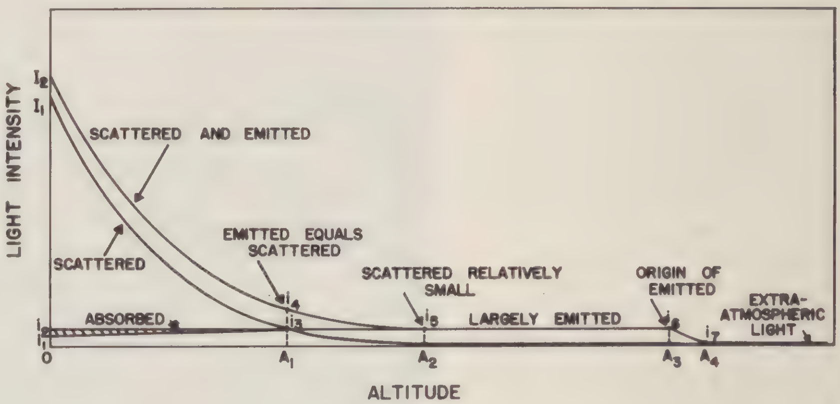

Figure 7

According to different theories, night airglow may originate from one of the following: (1) stored potential energy, particularly from photochemical reactions, (2) recombinations made possible by the dissociations and ionizations produced by the ultraviolet radiations from the sun, and (3) particles from outside the earth's atmosphere, possibly from the sun.

Day airglow is probably largely emitted light due to an absorption and emission process taking place in atoms and molecules under certain conditions. Thus, at various levels in the atmosphere, the sun's energy is absorbed by a particular kind of atom or molecule and then radiated in all directions.

The emission process which causes day airglow may be of two types. First, a very slow emission (based largely on the recombination of ions) which continues for a long time, even through the night. This is termed "night airglow" and, although very weak, it can be measured from the ground at night during the absence of the scattered light present in the daytime. However, the measurements presented in this paper have shown the day airglow to be of the order of ten thousand times the night airglow. This suggests that a second type of emission may be present--namely, a fluorescent type. That is one which takes place only while the atoms or molecules are absorbing at the same time they are emitting. Thus, when the sun is not shining on the upper atmosphere, the emission of this type ceases. On this basis, the night airglow might be considered to be largely what is left over of the day airglow (of one contributing factor of day airglow).

Plans for Future

The program now under way at the Geophysics Research Directorate, Air Force Cambridge Research Center, includes a study of the diurnal variation of the day airglow, using rockets and correlation with night airglow measurements. Equipment for studying night sky radiation is presently being set up at Sacramento Peak, New Mexico, under the supervision of Dr. F. E. Roach, Naval Ordnance Test Station, Inyokern, California, and will be used to correlate with day airglow measurements made from rockets fired as close to dawn as possible.

High altitude balloons will be used to study sky, earth and solar radiation, utilizing spectrographs and photoelectric detectors.

Discussion:

Dr. Tousey inquired if Dr. Edwards had analyzed his photographic records photometrically to determine sky luminance for comparison with sky luminance measurements obtained in other ways.

Dr. Edwards replied in the negative.

Dr. Tousey then asked if Dr. Edwards had considered the possibility that the apparent clouds might be Mie particles produced by gaseous discharge from the rocket.

Dr. Edwards stated his belief that the clouds could not have been produced by the rocket, since the burden of evidence from many photographs was that the clouds appeared at a higher altitude than the position of the rocket. However, he admitted that Dr. Tousey's suggestion might have merit and that indeed the "clouds" might have been produced in this way.

MILITARY VISIBILITY PROBLEMS

S. Q. Duntley
Visibility Laboratory
Scripps Institution of Oceanography

The Visibility Laboratory is one of the hosts of this meeting and, as such, it takes great pleasure in welcoming you to San Diego. We at the Scripps Institution of Oceanography are indeed honored and feel a great sense of pride that the Executive Council has brought the meeting here to see our laboratory, to hear what we are doing, and to make you acquainted with it. I think I can introduce the spirit and general purpose of the Laboratory in no more concise nor accurate fashion than to read a paragraph from the program brochure:

> The establishment of the Visibility Laboratory at the Scripps Institution of Oceanography of the University of California was accomplished subsequent to the recommendation of the Vision Committee at its 29th meeting for the creation of "...a central laboratory staff...directed by an advisory panel of the principal specialists in the visibility of military and naval targets...to deal with visibility problems from the entire Department of Defense and...serve as an officially recognized central clearing house for pertinent data and problems." This new laboratory, jointly and equally supported by the Navy and the Air Force, occupies three buildings on the grounds of the Navy Electronics Laboratory. By its creation, the recommendations of the Committee have been put into practice.

The current program and plans of the Visibility Laboratory are to be presented at this meeting in the expectation that the Vision Committee, as a permanent advisor, will contribute greatly to the effectiveness of the new laboratory throughout the months and years ahead. It is the purpose of my talk to present the background and the program of the laboratory.

For the benefit of those persons who have not attended the Vision Committee meetings before, it is timely to make clear what is meant by military visibility problems. We are not talking about the weather report or anything that the meteorologist ordinarily tells the military; our work is not the customary interest of the ophthalmologist; we are not concerned with the screening of personnel, or with the administration of eye tests, or with many other things which the Vision Committee discusses frequently. We <u>are</u> concerned with the ability of perfect eyes, the best in the Fleet, the best in the Air Force, or the the best in the Army, to detect the presence of military objects and to recognize them.

As an example of a military visibility problem, I have here an aerial photograph* of a submarine submerged to snorkel or periscope depth. We have been asked by the Navy to specify the circumstances under which such a fully submerged submarine is visually detectable from the air. This is one of the problems to which the Visibility Laboratory has addressed itself over a considerable period of time; it is a problem to which we now have answers. Similar problems concerning mines, reefs, and wrecks have come to our attention for quantitative answers to be used by military planners.

Next let us look at a photograph taken in San Diego harbor. Consider first the headland, Point Loma. This is a large object in every sense of the word. It is one of our problems to predict the maximum range at which such a landmark is visually detectable, under given atmospheric and lighting conditions. Consider next the aircraft carrier. It is not as big as Point Loma, but still it is quite a large object. Typical questions might be:

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*Photographs not available for reproduction in The Minutes.

At what maximum range can this ship be visually detected by night or by day, in fair weather or in foul, from the surface of the sea or from the air? There are smaller craft in the picture, and there are some specks which may be aircraft. All of these are of importance in military planning and they define visual tasks which constitute military visibility problems. We are interested in visual detection from air to ground, ground to air, air to air, surface to surface, air to submerged object, and visibility by swimmers. It is the purpose of the remainder of my talk to show how our laboratory is expected to deal with these problems.

This work started a long time ago; it went through war years when all sorts of spectacular new detection devices came into being. Throughout the war we were continually told that the day of the eye was over, that it would not be necessary to know how far objects can be seen, because no one would look any more. Time has not proved this to be true. All things have their limitations and all things have their uses. In order better to realize the rightful place of the eye in military practice, please imagine yourself in a world in which electronic devices for the detection of distant objects have been known and used exclusively for a long time. From childhood we have used nothing but electronic devices to detect distant objects; this is the means to which we are accustomed. Under these circumstances, suppose that someone should invent the human eye. Here is a device which is only about a cubic inch in volume; it weighs about 30 grams or so; it has a detection capability which enables a fighter plane to be detected at 10 miles or a bigger plane at 30; it will operate over 9 log-cycles of signal strength without a single manual adjustment—there isn't a knob on it. The associated power supply is independent of the power supply of the vehicle that carries it. This power supply can be charged with enough initial energy to operate it for many hours without having to do anything more in the way of supplying energy to it. The eye has many wonderful features. If we attempt to write a catalog description, the result is perfectly amazing: Our product can obtain information not only by the geometry but also by the color of the light; it has a spatial resolving power of the order of a minute of arc; it incorporates a double-sensitive screen; it has built-in autocorrelating mechanisms which give it an exceptionally favorable signal-to-noise ratio. All of this and much more is in just a single mechanism. The production problems are all solved; there are no strategic materials! Talk about top-secret military gadgets! Just imagine this thing!!! It is not at all surprising that the eye is useful in military practice. We must, therefore, learn as much as possible about the military capabilities of this detector. It is to this problem which the Visibility Laboratory addresses itself.

It is well to talk a little about the background of the work which goes on in the Visibility Laboratory, because only by knowing this background can one really understand the planning, the personalities, the hopes, and the purposes of the new laboratory. My personal interest in the subject, I believe, goes back to 1936 when, as a graduate student at M.I.T., I took a course in Illuminating Engineering taught by Professor Parry Moon. In that course, Professor Moon taught how to compute the minimum size and contrast of letters and numerals required to make a sign legible at some given distance down the street. No allowance was made for atmospheric clarity or other environmental effects; the calculations were based, in part, upon visual data that had been obtained by some of Moon's students. It seemed to me in 1936 that these data plus the others in the literature were sufficient for the solution of all visual detection and recognition problems. How naive can one be? This beginning, nevertheless, left in my mind the concept of taking physical data concerning the nature of the numeral, such as size, contrast, and light level, and combining these with known properties of the human eye by calculation to determine how far away the numeral can be read. This concept intrigued me so much that in the fall of 1940, when the Corps of Engineers asked for help in connection with the design of camouflage against the optical bombsight, I proposed an extension of this method as an engineering solution for their problem.

In those days the Norden bombsight was one of the top secrets of the USAF and it was one of the top espionage targets of our enemy. A prime question was, of course, how far and from what altitudes could the bombardier recognize the targets he was about to bomb. The Air Force believed that precision high-level bombing would be one of the hallmarks of its activities if war came, and the Corps of Engineers were planning defenses against enemy attacks of the same kind. There seemed to be sufficient information about the properties of the human eye to enable suitable calculations to be made provided the optical signal reaching the eye could be specified. Such specification required knowledge of the optical nature of natural terrains and the transmitting properties of the atmosphere along slant paths. With these requirements in mind, the Corps of Engineers established a project intended to obtain the necessary physical data concerning the optical environment in which the bombsight operates. I will not attempt here to recount the work done by this Army project in the days before the United States entered the war except to say that the central experimental approach involved a special spectroradiometer for use in an aircraft. With the advent of war, this work was transferred to the Optics and Camouflage Division of the NDRC, and thereunder the special spectroradiometer was built by the Research Laboratories of the Eastman Kodak Company. Subsequently this device, known as the Spectrogeograph, was flown by the USAF in a B-17 aircraft. At war's end, the Spectrogeograph became the property of the Navy and, through the courtesy of the Naval Research Laboratory, it is now at the Visibility Laboratory being made ready for further use. After conversion from a photographic to a photoelectric instrument, it will be flown again in Air Force aircraft. Much basic data that we were unable to get during the war is expected to be forthcoming from these flights.

It was found that the literature did not contain enough information about the eye to enable military visibility calculations to be made. To fill this gap a research program for the measurement of contrast thresholds for unaided binocular vision was set up at the Tiffany Foundation at Oyster Bay, Long Island. The observers looked at projections on a screen, and the data were electrically recorded. Dr. Blackwell, who will follow me on this program, performed the Tiffany experiments. He will review what was done at Tiffany during the war and also tell of continuing work which is still going on in his laboratory at the University of Michigan. Without the continuing work at Michigan, the Visibility Laboratory here would be quite unable to carry out its purpose.

Throughout the war and in the years that have followed, several other research teams have been at work on these problems. It will be possible to mention only a few. The research laboratories of the Eastman Kodak Company conducted a study of color contrasts; these were found to be nearly negligible compared with brightness contrasts under most circumstances, but they are important when the brightness contrast is nearly absent. The Naval Research Laboratory, under Drs. Hulburt, Tousey, and Stewart, has done a great deal of very basic and important work on the visibility of Naval targets. They have measured visual thresholds and they have been leaders in research in atmospheric optics. Some of the most important contributions have been, and continue to be, products of their laboratory. Within the Navy, CDR. Dayton Brown has been at work for a long time on the problem of aircraft camouflage and aircraft visibility, as well as submarine camouflage and submarine visibility. Much of this work was done here in San Diego with the Fleet. CDR. Brown was responsible in large measure for the painting doctrine for Navy airplanes and Navy submarines throughout the war and subsequently. There was work at Ft. Belvoir by the Corps of Engineers; there was work in the Air Force; there was work by several contractors of OSRD. Time will not permit these contributions to be described here. A milestone in the art of military visibility calculations was the production of the so-called Tiffany nomographs. These are charts by means of which one can find the limiting distance at which certain types of military targets are just visible. Such nomographic charts are today the principal tool for the solution of military visibility problems. We have other charts of improved design today, but the Tiffany charts are still very useful.

An interesting property of these charts came to light one day in January of 1945 when Dr. Irvine C. Gardner of the National Bureau of Standards visited the Tiffany Laboratory. Assigned by NDRC to talk with Dr. Gardner on that day, I discovered that he was concerned about the evaluation procedures then being used by the Armed Forces in testing binocular aids to vision. It amounted to comparing binoculars by looking through them. At first thought, that would appear to be an excellent and direct test. But in practice there are so many different visual tasks and so many unusual circumstances encountered by the military that opinions are diverse, nonquantitative, and open to all sorts of uncertainties. Dr. Gardner wanted a quantitative type of evaluation of these instruments which could lead to design improvements. He asked if any of the work done at Tiffany could be used for this purpose. During our conference I began to reason that it is the sole function of perfect binoculars to increase the effective area of the object and to do nothing else. Since area is one of the variables in the Tiffany nomographic charts, one can allow for the magnification of binoculars simply by introducing in the calculation an increased value of target area. The increase in area is proportional to the square of the magnifying power of the binoculars. This enables a prediction of what perfect binoculars can do; if one knows how to allow for such imperfections as contrast loss, brightness loss, and aberrations, he ought to be able to predict what real binoculars can do, and evaluate design changes in terms of performance on military visual tasks. Such an approach fitted perfectly with the program of Dr. Howard Coleman's Optical Inspection Laboratory of the Pennsylvania State College. Later a set of the Tiffany charts was sent to Dr. Coleman, who used them in just the way I have described to study a set of data that were taken by a very elaborate experiment at sea, conducted by the Navy at New London. The results of these out-of-doors tests, conducted primarily at night, were explained by predictions from the Tiffany nomographic charts. This work stands today as one of the important field verifications of the validity and usefulness of our method of attack on military visibility problems.

Encouraged by the success of the analysis of the New London data, the Vision Committee's subcommittee on binoculars recommended that Dr. Coleman's laboratory review the literature of binocular design and endeavor to evolve a technique for making binoculars for specific visual tasks. A number of disquieting questions came up when this work was undertaken. Several of the scientists from abroad who knew of the work in atmospheric optics that had been done in Germany, particularly during the war, began to question the Koshmeider equation for the brightness of distant objects. If this were true, the simple exponential law for contrast attenuation which I had worked out during the war might be invalid. None of the available data could definitely settle the question. Because my exponential equation was built into the Tiffany nomographs, Dr. Coleman felt obliged to test the validity of the law before he could proceed with his main task. He did this after the war at the University of Texas with excellent equipment. His results fully supported the equation and the nomographs.

During the post-war period there was some question here within the Vision Committee about whether visual thresholds measured in a laboratory would be the same as thresholds which apply outdoors with real objects and real landscape backgrounds. Dr. Blackwell's laboratory at the University of Michigan undertook a very major out-of-doors experiment to investigate this matter. He found that laboratory thresholds do apply in the field; this work has been fully reported to this Committee at previous meetings.

In the post-war years the Navy became very interested in the visual detectability of fully submerged submarines lying at shallow depths. The Vision Committee was asked by the Bureau of Ships and by the Office of Naval Research to endeavor to specify a space volume above the surface of the sea within which an aerial observer can see the submerged submarine if he looks in the right place. This turned out to be a hard problem to which there was no ready answer. After a considerable amount of discussion, it was decided that someone must explore the physical factors which limit the visibility of submerged objects. An ONR contract was let with M. I. T. under which was established what we called

the Visibility Laboratory. Work in this laboratory has gone on for nearly five years; it has not been limited entirely to the visibility of submerged objects, but it has touched many related fields. Answers to several different military visibility problems have been given to the Armed Forces. Some of the results of this program appear in the final report of the M. I. T. contract. This report has just come from the press and will be available for distribution as soon as we add a distribution list and an errata sheet. The M. I. T. program had as one of its goals the production of a handbook for use by submariners which would show space volumes for a wide variety of operational circumstances. This was not achieved during the time that the contract was at M. I. T., but it is one of the goals of the new Visibility Laboratory here in San Diego.

About two years ago, there was a flurry of interest in certain military visibility problems within the Air Force, notably by the Strategic Air Command. The most pressing of their many problems concerned the air-to-air visual detectability of big bombers. This problem had aspects for which we had no answers. In the first place, we had very little information about the inherent contrast of aircraft at high altitudes. In the second place, we had no data on atmospheric clarity aloft. After a year of fairly ineffectual working group activity, a more active approach to the problem was recommended by the Vision Committee at its 29th meeting. It was felt that major military visibility problems were bound to appear from time to time throughout the Department of Defense. Each of these would require a new research contract, the assembly and training of a new research staff, and consequent delays in providing answers. All this could be avoided by the creation of a permanent central laboratory with a trained, permanent staff to which the military or Vision Committee working groups could turn for answers to military visibility problems. The Committee recommended the enlargement of the Visibility Laboratory at M. I. T. for this purpose. Both the Navy and the Air Force proposed to provide new and larger facilities for this enlarged laboratory and they agreed on initial priority for the problems of the Strategic Air Command. In doing this the Visibility Laboratory has been transplanted here in San Diego where there are unmatched facilities for field work at sea, in the air, and on land. There are more than 300 days per year of outdoor weather. Operating units of the Air Force and the Fleet can provide services better here than anywhere. Furthermore, the Scripps Institution of Oceanography of the University of California has a more direct and valid interest in environmental optics than any other academic institution.

Before describing the new laboratory, however, I should report the status of the work for the Strategic Air Command. As many of you know, Dr. Hulburt made a very great contribution to the problem by surveying the whole matter of sky brightness, particularly at high altitudes, at night and in twilight. He has put together all available data, filling in the gaps by means of the sky brightness theory of which he and Dr. Tousey are the authors, thus producing consistent tables which represent the best information about the distribution of sky brightness at all solar altitudes, all observer altitudes. These tables have served as the cornerstone for the calculations which we have been able to do for the Strategic Air Command.

Recently there has been a major effort to get daytime sky brightness data by the Naval Medical Research Institute of the Bureau of Medicine and Surgery. Throughout an extensive flight program, sky brightness and illumination on aircraft surfaces have been measured under a wide variety of daytime conditions at altitudes ranging from 1,000 to 50,000 feet. Yesterday, Capt. Wilbur E. Kellum, Commanding Officer of the NMRI, handed me a pre-distribution copy of the first of a series of reports that will issue from this program. This first report concerns sky brightness only on clear days. Other weather conditions will be treated in later reports. These data will doubtless become very valuable in connection with aircraft visibility problems.

The time has now come to speak specifically about the plans of the Visibility Laboratory. Figure 1 shows a program diagram; it has three basic parts: First, there are

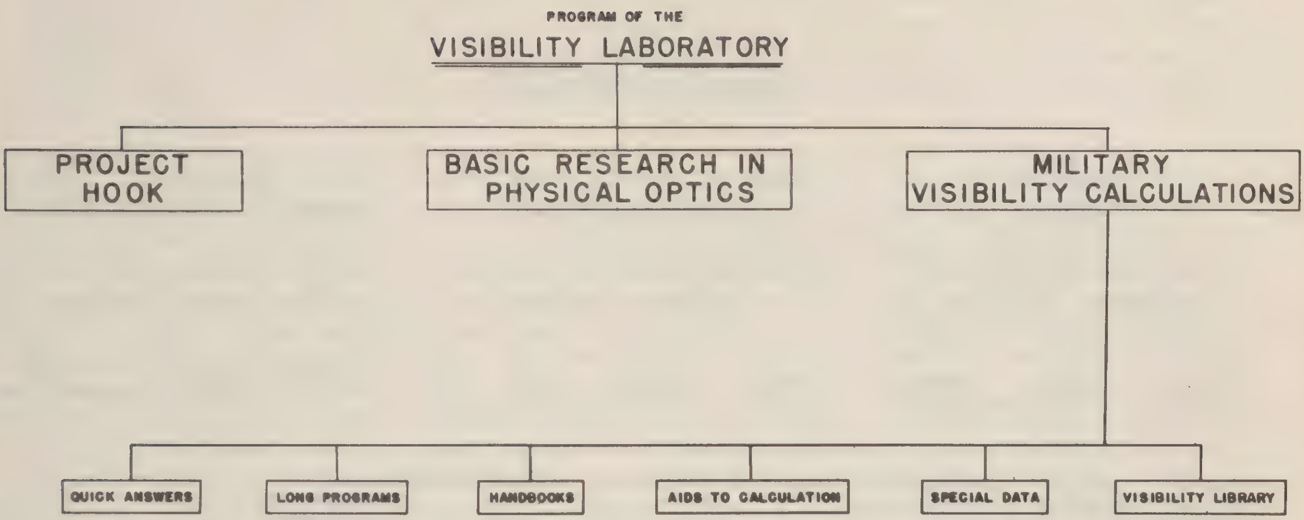

Figure 1

military visibility calculations, including those about which I have been talking; second, there is basic research in physical optics, and third, something called Project Hook which Mr. Tyler is going to describe later. The program of basic research in physical optics is a very vital and necessary adjunct to both the military visibility calculations and Project Hook. Actually, it represents the biggest part of what is being done in the laboratory. The term "environmental optics" is a more accurate and a more descriptive title for our research activities. We are interested in the environmental optics of the atmosphere, the ocean, and the surface in-between. Some of the details of the military visibility calculation program are shown by Figure 1. First is the "quick answers" department. A problem came in only last night on which we have promised answers within a week; the capability of the laboratory to do this sort of thing will mount as our personnel becomes trained and data is collected. Then there are "long programs," like the Strategic Air Command problem mentioned earlier. We have given SAC so many quick answers that it has become a long program. Next are handbooks, like the handbook for submariners which I mentioned previously. In order to do handbooks, we have to develop special aids to calculations, special nomographs, special tables, and computing devices.

Special data are obtained by field experiments and flight tests, and by extraction from other people's work. For this we need a library of reports. This is, perhaps, one of the most important parts of our whole planning. Because of our terms of reference from the Vision Committee, we hope that others will send us their reports and their data so we can become a center of visibility information and pertinent data. This is one of the reasons for bringing the Vision Committee to San Diego to see our laboratory. We hope that the data we so much need will be sent to us. We know that much valuable information exists in certain operational documents. The greater our access to such data, the more valuable can be our work on military visibility problems. We hope to be able to furnish each of you with data when you request it; we hope to be a central data clearing house for the whole Department of Defense in this regard.

Figure 2 contains some details of our basic research program in physical optics. We live near the surface of an ocean of water and we live near the bottom of an ocean of air; these two oceans have an interface. All three have optical properties of importance in military visibility calculations.

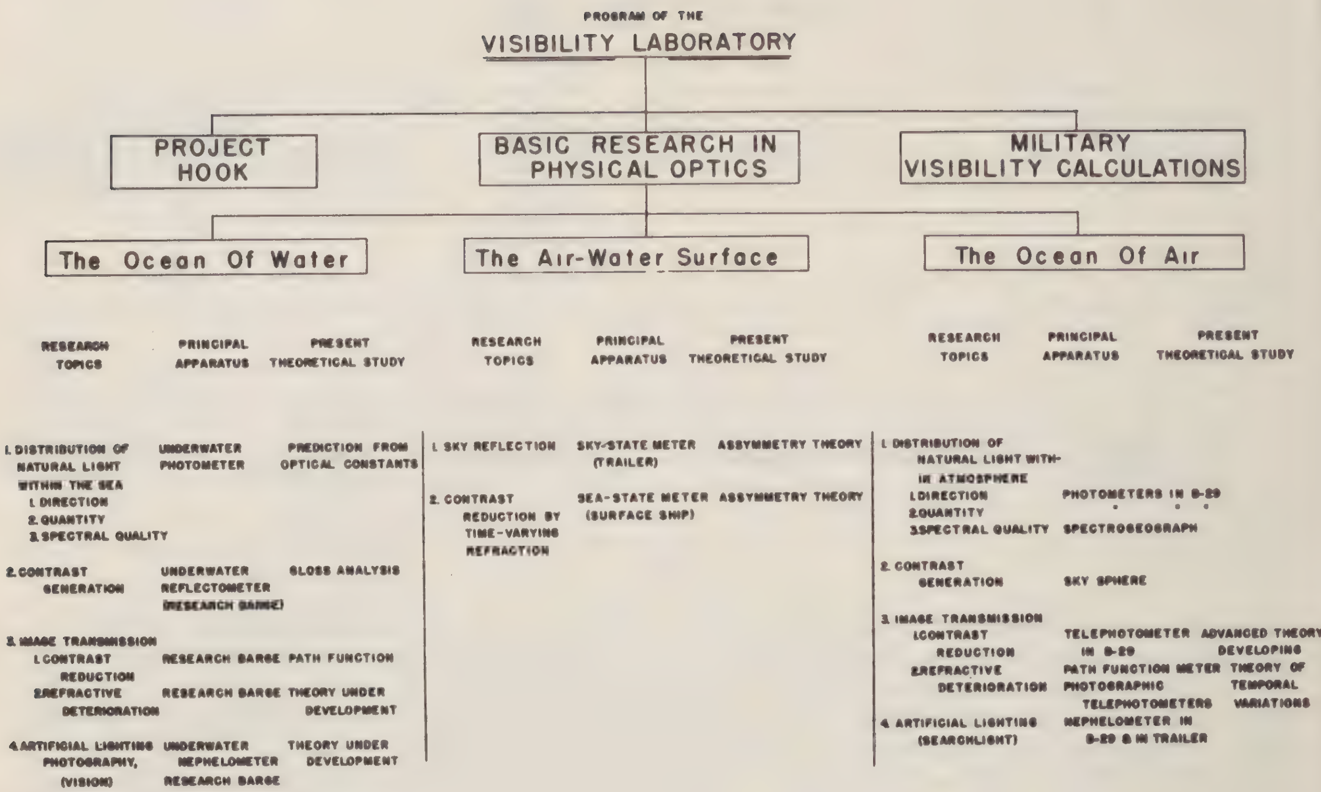

Figure 2

Consider first the ocean of water. We are concerned with distribution of natural light within the sea from the standpoints of direction, quantity, and spectral quality. All this is being studied with an underwater photometer from Scripps' ships. We are also working on the theory of a simple means for obtaining the pertinent optical constants of sea-water on oceanic survey voyages.

We are interested in contrast generation by submerged objects. This, after all, is the initial optical signal that makes visual detection of submerged objects possible. Unless the inherent contrast is known, all other information is useless. Underwater reflectometers in our research barge at the field station at Diamond Island are being used to study the gloss characteristics of submerged surfaces. Studies are also in progress of contrast reduction by the water, of the refractive deterioration, of image quality by such optical inhomogeneities as plankton. Again, theory is under development. Occasionally questions arise about artificial lighting, as in photography under water, and here we are using an underwater nephelometer on our research barge. Theory is under development.

For every one of these items in the sea there is a corresponding item in the air, as Figure 2 will show. The same basic differential equations which govern the passage of light and images through the atmosphere govern their passage through the water. The experimental techniques are different; the constants in the equations are different. Some terms are more important in the air than they are in the water, and vice versa.

The research program on the interface between the air and the water involves the study of sky reflection of the time-varying refraction caused by water waves. The Vision

Committee has heard accounts of both of these topics and nothing more need be said except that Scripps' ships are being used for surface experiments, and extensive equipment is being mounted in a trailer that can be taken to sea as a deck load or taken to the desert or to a mountain top, or wherever it is needed in order to get interface data at ground level or sea level.

The laboratory is budgeted for a staff of twenty-five. This provides for 1000 man-hours per week. 600 of these hours are to be devoted to instrumentation by shop people; and 400 man-hours per week are to be provided by scientific personnel who will do the research on the military visibility problems. Although the laboratory has been operating since September 1952, we have not yet had a staff of this size. We have had, moreover, the misfortune of having the personnel roster fill in first at the bottom. This has left the top nearly empty much of this time. We have actually averaged less than 80 scientific man-hours per week thus far. Fortunately, the individuals who came from the Visibility Laboratory at M. I. T. were thoroughly trained in our work. They have been able to do much to fill the gap. We have tried to make the output of the 80-man-hour crew resemble the output of a 400-man-hour crew. Although this result has not been entirely achieved, I am rather proud of what has been done per man-hour. The personnel situation is improving rapidly; some of our top-level people came aboard only this week; others are expected within a few days. None have been in the laboratory long enough to be fully indoctrinated. As soon as the Vision Committee meeting is over, I expect to launch a teaching program similar to the special course which I gave to the Visibility Laboratory staff at M. I. T. two years ago. Past experience leads me to expect this teaching to be highly rewarding.

The laboratory occupies three buildings. There is a machine shop and dark-room building and two laboratory buildings with offices on the second floor of both of them. The Vision Committee will visit these buildings this afternoon as well as the waterfront area where the Scripps' research ships and some of our apparatus will be seen.

In making its visits to the laboratory, the Vision Committee has a responsibility to ascertain whether the facility that has been created is doing the job that the Vision Committee has asked to be done, and which the Navy and Air Force want done. Please remember that the Committee recommended a central laboratory for the entire Department of Defense. Up to a year ago, the Visibility Laboratory was purely a Navy activity, supported by ONR and by the Bureau of Ships; today the Air Force is also giving support. Occasionally, the laboratory gives service to other agencies in the Department of Defense, but it will not really be a three-services facility until it is supported by all three. We hope, therefore, that there will eventually be active participation by the Army. This is not a plea for a bigger budget. We do not desire to be a big organization. The laboratory is not looking for work, but it agreed to do a job and it stands ready to do it.

When you go through the laboratory this afternoon and look at our equipment and our nice buildings, meet our staff and see our present activities, I hope you will not limit your thoughts to what is now there; I hope that each of you will do some dreaming for us. Can this new laboratory fulfill the Committee's expressed desire for "a central laboratory staff directed by an advisory panel of the principal specialists in the visibility of military objects and naval targets to deal with visibility problems for the entire Department of Defense, and to serve as an officially recognized clearing house for pertinent data and problems?" What further steps, if any, need to be taken? We would like to regard every member of this Committee as a consultant and advisor to the Laboratory. Indeed, the Vision Committee will always be the principal advisor in our work. The ultimate success of the Visibility Laboratory will be due in very large measure to the help it receives from the Armed Forces and from the Vision Committee.

RECENT LABORATORY STUDIES OF VISUAL DETECTION*

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INTRODUCTION

This report is a review of the visual detection studies undertaken in recent years at the Vision Research Laboratory of the University of Michigan. The visual detection program has been organized to provide the psychophysical data required in various military visibility problems. These data are intended to supplement data on the physical stimulus provided to the eye by military targets seen through atmosphere or water, which data is to be provided by the Visibility Laboratory of the Scripps Institution of Oceanography.

The present program is intended to be co-ordinated with the studies reported by Dr. Duntley so that military visibility problems may be solved with satisfactory precision and promptness. The co-ordination of effort of these two laboratories represents a "marriage" of scientific endeavor which dates back to World War II research programs conducted under the auspices of Section 16.3 of the National Defense Research Committee.

Dr. Duntley has indicated the grand design for the two research programs. The essential notion is that if we have psychophysical data on the detection capacity of the eye, physical information on environmental optics, and techniques of computation, we will be able to predict visibility ranges for many military targets. The objective of the research is therefore to provide visual detection data for use in visibility predictions. These same studies can be looked at from a theoretical point of view but the theoretical aspects of the problem will be ignored in the presentation to be made at this time. The data we have collected to date will be reviewed, some of which are familiar to members of the Committee, but most of which are new. Such a review will show how far we have gone in obtaining the information Dr. Duntley needs in setting up his computation machinery.

THE TIFFANY RESEARCH

The present program of visual detection research had its beginnings in the Tiffany Foundation program of World War II. This research was reported to the Vision Committee at the 15th meeting. It will not be necessary to exhibit these data again. It will be worthwhile, however, to review the conditions under which the Tiffany data were collected, so as to place the new research in the proper perspective, to show how it differs from the Tiffany research and how we believe it represents a real advance over the earlier studies.

The Tiffany visual detection data were collected during the years 1943-45 and were an attempt to provide data for immediate use in making visibility predictions. There were three programs at Tiffany which differed in detail. It will be profitable to review the variables studied and the experimental conditions used in these programs of measurement.

The first program involved a search procedure. At the time, this was considered to be the most practical kind of experiment for use in military visibility predictions, because at that time certain scanning and searching procedures were standard within the military services, at least within the Navy. The targets could occur in any one of eight possible spatial positions, spaced uniformly on a 15^{o} orbit. The observers were required to search

*This research was sponsored by ONR Contract N5ori-116, Task Order V, and by BuShips Contract NObs 54342.

the orbit and to indicate that they could detect the target by correctly indicating the spatial location it occupied. The observers knew when the target was going to appear. The observers knew approximately where to expect the target, because there were only eight possible locations on the orbit in which the target could appear. We cannot be certain how the observers scanned the orbit on which the target could appear. Perhaps their fixation moved along the entire orbit. Perhaps the observers moved their fixation among the eight possible target locations. A 6-second search period was allowed, because scanning the 15° orbit in this period of time represented the then-standard scanning rate adopted by the Navy.

The targets were circular in form and of uniform luminance. The targets represented increments to the luminance of the background and will be called "bright targets" for convenience. The variables studied were the size of the target and the luminance of the background. The observers were allowed to use any mode of viewing which they found most efficient, and we khow that they used direct foveal vision at high luminance, and peripheral or off-center vision, at low luminance. We do not know which they used at intermediate luminance levels because we did not record eye movements during observations.

The second program at Tiffany was similar in all respects, except that the targets represented luminance decrements. These will be called "dark targets." All other conditions were identical between the first and the second programs. In referrring to target detections, it is convenient to define target contrast as

$$C = \frac{\Delta B}{B} \tag{1}$$

where C = contrast

ΔB = difference in luminance between target and background, expressed as a positive number for either bright or dark targets

B = background luminance.

It was found that, under most circumstances, bright and dark targets of equal contrast had equivalent detection probabilities.

The third Tiffany program differed from the first two markedly. It was intended to represent the limiting case where the observers had indefinitely long to look for the target. They were told precisely where the target was to appear, and they were given a sufficiently long time to detect it so that doubling the time of exposure did not increase the probability of detection. To satisfy this requirement, very long durations were required, ranging from 8 to 20 seconds. The targets all represented luminance increments to the background. Target size and background luminance were varied as before.

In these experiments, the observers merely said "Yes" if they detected a target and "No" if they did not. This procedure obviously differed from the procedure in the first two programs, in which the observers were required to identify the spatial location of the target. The data of the third program have been built into the Tiffany nomographs which have been described by Dr. Duntley.

Toward the end of the Tiffany program, a few preliminary experiments were performed which were intended to generalize the results in several directions, in order to make them more practically applicable to military visibility problems. Targets are seldom uniformly bright, round discs. (This was before the advent of "flying saucers.") We wondered to what extent one could generalize from the targets we had studied to more realistic military targets. We did a few "quick and dirty" experiments, using ship photographs. We did a few experiments to ascertain the effect of dark horizon lines in the neighborhood of the

target, of the sort one would encounter in the case of a ship sighted along the horizon. We also did some preliminary work on the effect of target shape.

These studies represented the termination of the Tiffany program on visual detection, and in 1945 the Tiffany Foundation was disbanded and later demolished. The basic Tiffany data of the three main programs have been published in the open scientific literature.[1] The results of the preliminary experiments have not been published. In the seven years since 1946, the work has been continued at the University of Michigan. It is the principal purpose of this paper to review the progress of the Michigan research to date.

THE MICHIGAN RESEARCH

Preliminary Experiments

A number of preliminary experiments were conducted between 1946 and 1950 under sponsorship of the Office of Naval Research. The first of these was the field test to which Dr. Duntley has referred. The results of this test were reported to the Committee at the 23rd meeting. Measurements of visual detection were made in an outdoor facility in northern Michigan. The test demonstrated to our satisfaction that, when the conditions of measurement are exactly the same, laboratory data and data collected in the field are identical. This may seem almost a truism. Actually, there are many apparent differences in how things look outside and in the laboratory, and it is not obvious that these apparent differences are of no practical significance in detection probability. For this reason, we considered our research a validation study of the procedure of working in the laboratory and using the data to predict the visibility of military targets. Since the conclusion of the field test, we have concentrated entirely on the laboratory and have no plans for returning to the field. We find that we can measure more thresholds in one afternoon in the laboratory than in six months in the field, so we have no enthusiasm for field measurements unless they become absolutely essential.

The second preliminary experiment concerned the method of measuring visual detection in the laboratory. We compared the procedure in which an observer has to identify some aspect of the target, such as its spatial location, with the procedure in which all he needs to say is "Yes, I see it" or "No, I don't." The results of this experiment have recently been published.[2] We found that there was greater day-to-day reliability of measurement and lower thresholds when the forced choice procedure was used.

Another preliminary experiment demonstrated that differences in viewing distance from 1.5 to 20 feet produced no difference in visual detection, provided we were careful about all experimental conditions, including particularly the refractive condition of the eye. These data justify us in working in the laboratory at any convenient viewing distance within the limits tested.

Between 1946 and 1950, we also developed equipment to reduce error and expense in making our laboratory measurements of detection. Basically, we have developed automatic equipment which presents a program of controlled light stimuli, which records the responses of subjects and tallies response correctness.

These preliminary experiments and developments have led to the adoption of a standard procedure which we have employed in nearly all our recent experiments. Before describing the recent experiments, it will be worthwhile to describe our standard procedure.

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[1] H. R. Blackwell. Contrast thresholds of the human eye. J. Opt. Soc. Amer., 36, 624 (1946).

[2] H. R. Blackwell. Psychophysical Thresholds: Experimental Studies of Methods of Measurement. Eng. Res. Bull. No. 36, University of Michigan Press, 1953.

The observers are required to indicate their ability to detect a target by correctly identifying the one of four possible time intervals in which it occurred. The observers are warned when a series of four time intervals is to begin. They are aware exactly where the target is to appear. Target presentations are made repeatedly at one contrast value and the probability of detection determined. Each of five target contrast values is used. These contrasts vary so that the probability of detection varies from chance (.25 with four possible time intervals) to nearly 1.0. The effect of chance successes is eliminated from the data on the basis of standard statistical conventions.

The observers are forced to choose a time interval as the most likely to have contained the target, even if they have no confidence of the correctness of their choice. This method results in significant numbers of detections without the subject having a high level of awareness of their presence. It may seem strange that we choose to measure detections which are made without awareness, since we are making our studies with the intention of applying the results to military detection problems, where the observers will certainly not report target detection without awareness. Our selection of the forced-choice method of measuring detection rather than a method involving a higher level of awareness depends upon the results of a preliminary experiment described above. It was shown that measurements made with forced-choice were more stable from day to day than measurements made by requiring observers to report detection with "Yes" or "No." However, use of the forced choice method does force us to evaluate the extent to which detection probabilities measured in this way differ from detection probabilities under field conditions. We shall present experimental evidence on this point subsequently.

The Main Experiments

The principal experiments now to be reported have all been carried out since 1950. Support for these has come largely from the Bureau of Ships. Support has come also from the Illuminating Engineering Society Research Fund, within the last month from the Air Force, and from various units of the University of Michigan—the Graduate School, the Department of Psychology, and the Institute of Industrial Health. Two of these experiments have been reported to the Committee previously and I will describe these only briefly. I do not intend to discuss the details of the experiments; my purpose is to review the areas of the experiments and the general nature of the results. It is my intention that such a review will suggest which problem areas are reasonably well covered and which areas require a great deal of additional effort before military visibility problems may be solved.

The first study was reported to the Committee at the 31st meeting. Detection probabilities were determined for each of four target sizes at each of a range of background luminance levels. Such a program of measurements was carried out for each of seven target exposure times: 1/1000, 1/300, 1/100, 1/30, 1/10, 1/3 and 1 second. All data were collected with the observers' eyes directed <u>at</u> the target at all luminances.

These experiments differ from the first and third Tiffany programs in two important ways. First, in the new experiments, we know in what portion of the visual field the target occurs. In both Tiffany programs, the observers used whatever portion of their visual fields they found to be most sensitive. Second, the target exposure is controlled and is varied systematically. In the first Tiffany program, the observers had to search for the target and hence we do not know what the effective time of target exposure was. In the third Tiffany program, we know that the target exposure time was long but we had no data relevant to the effect of varying target exposure time.

In solving different military visibility problems, we have use for the data at all exposure times. For example, the 1-second data have been used in connection with visibility problems involving a tank-mounted searchlight. The 1/1000-second data have been used in connection with visibility problems involving visual reconnaissance from high-speed aircraft.

A second experiment was conducted to establish our justification for extrapolating the data obtained in the first study to lower luminance levels than those actually used in the experimental study. The study was reported at the 31st meeting of the Committee and need not be described here in any detail. It was shown that the luminance difference between target and background required for a given probability of detection does not vary as the background luminance is decreased from low luminances to zero. This result implies that contrast is inversely proportional to background luminance at low luminance, a relation which may be used to extrapolate the data obtained at various target exposure times to as low values of background luminance as are of interest. (These results apply only to experiments in which the target always occurs in the foveal region of the visual field. If the target occurs in the peripheral visual field, such a relation would not be expected to apply, except at exceedingly low background luminances.)

The review of recent detection research which has previously been reported to the Committee is now complete. The studies now to be reported have not previously been reported to the Committee. These may be listed as follows: (a) Studies of target shape; (b) studies of spectral sensitivity; (c) studies of target area for monochromatic targets; (d) studies of peripheral sensitivity; (e) studies of aircraft models; and (f) studies of psychological variables.

a. Studies of target shape

All the experimental data reviewed here in detail were obtained with circular targets. Obviously, few military targets are circular. It is of considerable importance, therefore, to establish the relative detectability of targets differing in shape, and circular targets. Since target area is known to influence detection to a very large extent, it seems simplest to compare targets of different shapes which have equal area. Perhaps the first question is, to what extent is the detectability of a target dependent upon area alone, and independent of shape? Preliminary experiments at Tiffany suggested that shape was a much less significant variable than area, but that target shape does influence target detectability to a significant extent.

The present series of experiments was designed to investigate the influence of target shape in a comprehensive manner. The experiments are still in progress, but the early results may be of some interest. The research is being conducted in the Vision Research Laboratory by Mr. A. B. Kristofferson.

We began by searching for a theoretical formulation of target shape, in order to expedite the investigations of this variable. The theory attempts to predict the detectability of noncircular targets from the detectability of circular targets. We may begin with data relating the contrast required for some level of detection probability and target area for circular targets. Such data are presented in Figure 1. These data are the averages for 4 observers. The targets are viewed binocularly, with natural pupils. The exposure time is 1/100 second. The background luminance is 10 foot-Lamberts. The precise form of the relation between threshold contrast and target area has considerable theoretical interest, but we will not consider this aspect of the matter. We will

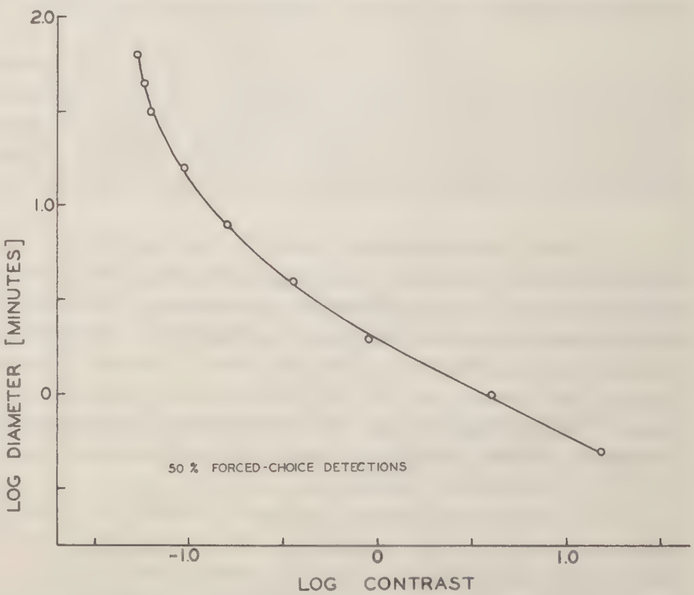

Figure 1. Average data for 4 observers. Circular targets.

simply use an analytic method of describing the effect of increase in size upon threshold contrast. It is obvious from the data in Figure 1 that as the size of a target increases, the contrast requirement decreases. There is a limit to this effect, when the target is very large. Under these conditions, the contrast does not continue to fall but reaches a lower asymptotic limit. On the other hand, at very small sizes we have a simple relation between size and contrast, which has been called Ricco's Law, in which area and contrast are reciprocal. Now between these limits of reciprocity and independence of the two variables, there is some kind of continuous dependent relationship. We have attempted to develop a mathematical model of this dependence which may conceivably have physiological significance. We must begin with an assumption as to the fundamental nature of the detection process. We assume that, for a target to be detected, an amount of excitation must be elicited at some point in the nervous system of a criterion amount, and we assume that this criterion is independent of the size of the target. Large targets have lower threshold contrasts because, being large, they receive contributions from various spatially separated parts of the visual system. This is a spatial summation effect. As the target gets larger, the outer annulus corresponding to the size increase contributes to the excitation produced by the center of the circular target, but as the target gets larger the amount of this contribution decreases, and we finally reach the point where making the target larger has no further effect on the threshold contrast. Rather than start with a theoretical model, we have proceeded analytically, and have determined the nature of the summative process empirically from the data in Figure 1. In effect, we determine from each point on the smooth curve of Figure 1 the decrease in threshold contrast brought about by an hypothetical annulus of area added to a given circular target by comparing the threshold contrast for that target with the contrast of a circular target composed of the target plus annular additional area. The decrease measures the summative contribution made by the annular area of interest. The summative contribution of an annular area within the range where Ricco's Law applies will be unitary. The summative contribution of an annular area, when the target is already very large, will approach zero. The summative contribution will vary between 1.0 and zero for targets of intermediate sizes in accordance with what we call the summation function.

This statement is qualitative rather than exact. One formula for computing summation contributions is:

$$S = \frac{1}{2\,RM^2}\,\frac{dM}{dR} \qquad (2)$$

where S is the summative contribution at a point
R is the target radius, and
M is the threshold contrast.

The summation function computed from the data in Figure 1 is presented in Figure 2. Once the summation function is available, we can compute the summative effectiveness of any target shape by integrating each element of area of the target against the value of the summation function appropriate to its position with respect to the center of the target. Assuming that there is no shape effect except the effect introduced through differences in summative effectiveness, we can predict the detectability of any target shape directly from the summative effectiveness. Of course, we must determine by experiment the extent to which

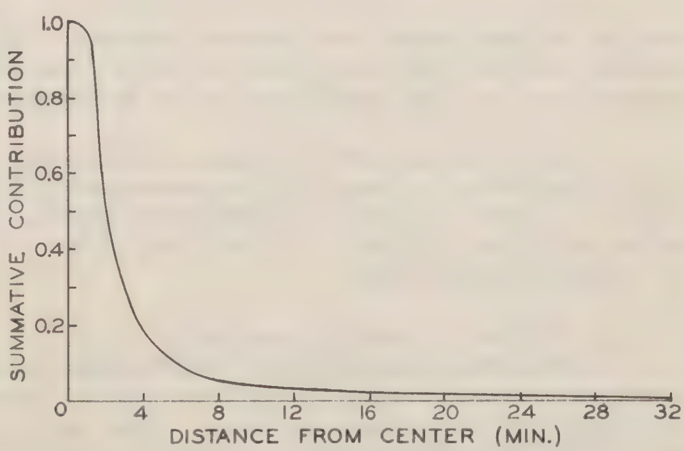

Figure 2. Summation function derived from data in Figure 1.

predictions of the detectability of non-circular targets are adequate. This is precisely what we have done. We began by obtaining the threshold data for circular targets, we then derived the summation function, then predicted the threshold contrast for a series of non-circular targets, and finally we actually measured the threshold contrasts for the non-circular targets to test our predictions.

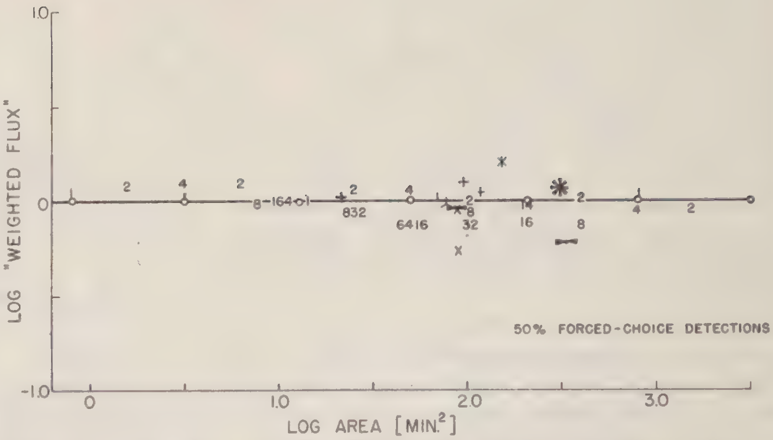

Figure 3. Data for non-circular targets. All symbols should fall on the solid curve if the thresholds for these targets agreed precisely with our predictions.

The overall adequacy of our predictions may be judged from Figure 3. "Weighted flux" is the flux required for detection threshold of a target multiplied by the relative summative effectiveness of that target. (Flux is the product of target area and target contrast.) Values of weighted flux for circular targets are indicated in Figure 3 by open circles. The values of weighted flux for the various non-circular targets which we have tested are indicated by the numbers and other unusual symbols in Figure 3. The numbers refer to rectangular targets; the number represents the ratio of length to width. The other symbols are direct representations of the non-circular targets studied. If the experimental data agreed precisely with the predictions, all the symbols would fall on the solid line. The data appear reasonably well fitted by the line and hence, we may conclude that our method of prediction has been reasonably successful.

The adequacy of our predictions may be more easily determined from the data in Table 1, where the ratios of the obtained to predicted values are presented. It is to be noted that the predictions are more successful for the rectangular targets than for other targets.

We regard the results to date as encouraging. We hope to discover the bases of the larger discrepancies between the obtained and predicted thresholds and when we do, our method of prediction may have to be more complicated than it is at present. Nevertheless, we believe that this line of attack will greatly reduce the number of targets we will have to study in order to provide answers to military visibility problems.

There is one implication of the theory we have used to predict the detectability of non-circular targets which is of special interest. The theory implies that the target having the greatest detectability with given area is a circular target. For given area, a target will become less and less detectable as the target dimensionality ratio is increased.

Figure 4 reveals that the data confirm this general prediction. Here we have plotted log threshold flux for each of our non-circular targets. The symbols are the same as in Figure 3. Note that all the symbols for the non-circular targets fall above the solid curve representing the circles. This means that no non-circular target was as visible as a circular target of equal area.

b. Studies of spectral sensitivity

A program of measurement of the spectral sensitivity of various parts of the central fovea is underway, under the direction of Dr. John H. Taylor. A number of preliminary measurements were made last year. The results of these measurements are presented to record the general relations we expect to find in our more complete measurements.

Table 1

RATIOS OF OBTAINED/PREDICTED THRESHOLDS FOR NON-CIRCULAR TARGETS

A. Rectangular Targets

Dimensions (min.)	Ratios	Dimensions (min.)	Ratios
1 x 1	1.09	4 x 4	1.05
1 x 2	1.26	4 x 8	1.15
1 x 4	1.35	4 x 16	1.10
1 x 8	0.96	4 x 32	0.87
1 x 16	1.07	4 x 64	0.76
1 x 32	0.87	8 x 8	1.05
1 x 64	0.71	8 x 16	1.00
2 x 2	1.10	8 x 32	0.98
2 x 4	1.29	8 x 64	0.71
2 x 8	1.07	16 x 16	0.98
2 x 16	0.87	16 x 32	1.04
2 x 32	0.71	16 x 64	0.93
2 x 64	0.76	32 x 32	1.12
64 x 64	1.00	32 x 64	0.94

B. Other Targets

Dimensions (min.)	Ratios	Dimensions (min.)	Ratios
2 x 32 cross	1.24	1 x 64 "22.5° cross"	0.90
2 x 8 cross	1.05	1 x 64 "10° cross"	0.55
1 x 64 cross	1.13	1 x 64 "bowtie"	0.59
1 x 32 3-legs	0.94	1 x 32 "bowtie"	0.91
1 x 32 6-legs	1.63	1 x 32 8-arcs	1.18

We measured the detection threshold for monochromatic point sources, presented against a black background. These data are relevant to the problem of detection of colored light signals, not to the problem of color recognition or identification. The measurements were made monocularly, using a 6 mm. artificial pupil. The targets were circular, and subtended 1 minute of arc. Target exposure time was 1/10 second.

Spectral sensitivity was measured for three locations within the central fovea, for each of three observers. The data are presented in Figures 5-13.

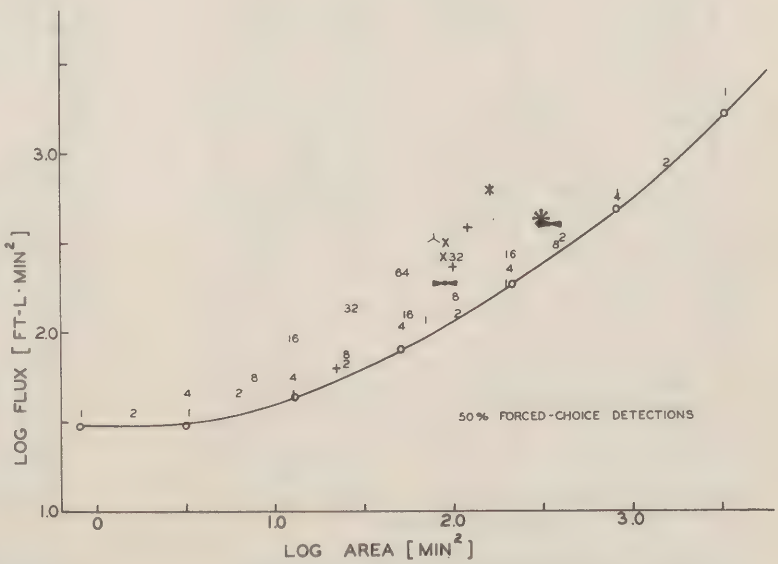

Figure 4. Data for non-circular targets. This plot reveals that circular targets are more detectable than non-circular targets with equal area.

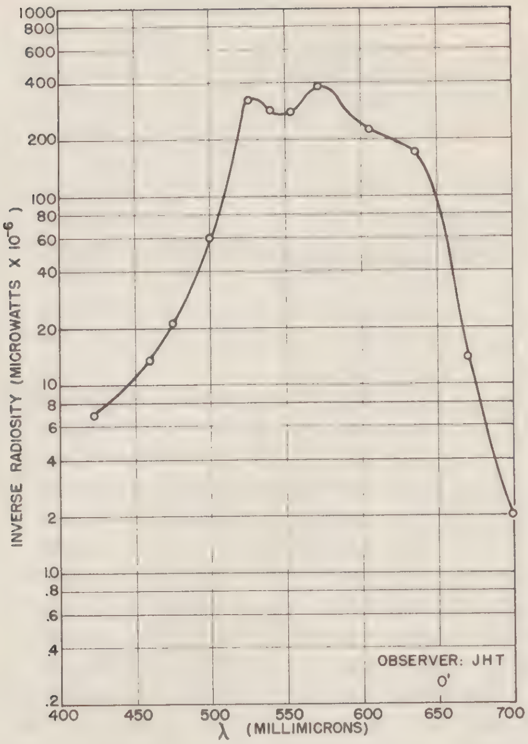

Figure 5. Point source spectral sensitivity data for observer JHT at the fixational center.

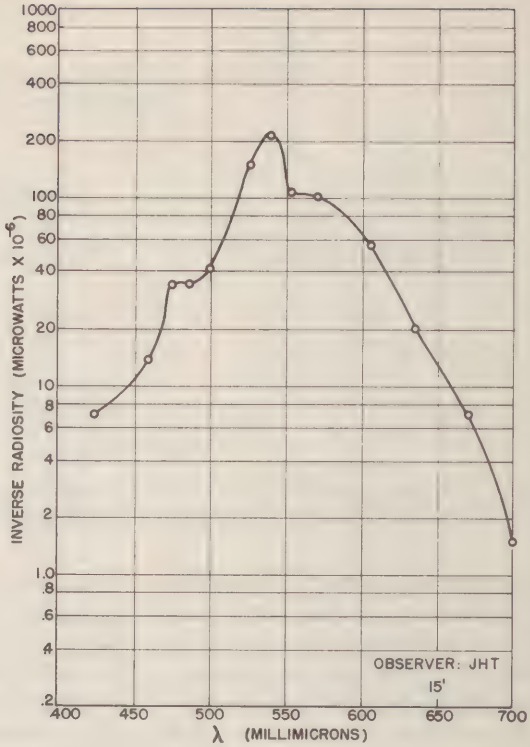

Figure 6. Point source spectral sensitivity data for observer JHT at a point 15 minutes from the fixational center.

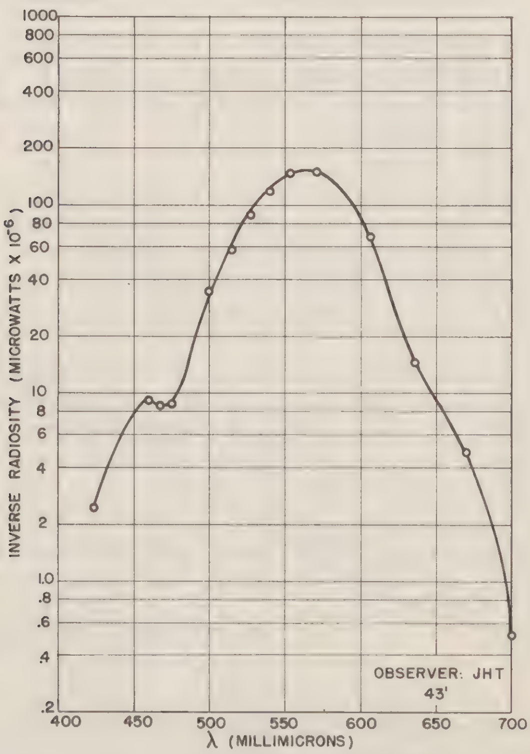

Figure 7. Point source spectral sensitivity data for observer JHT at a point 43 minutes from the fixational center.

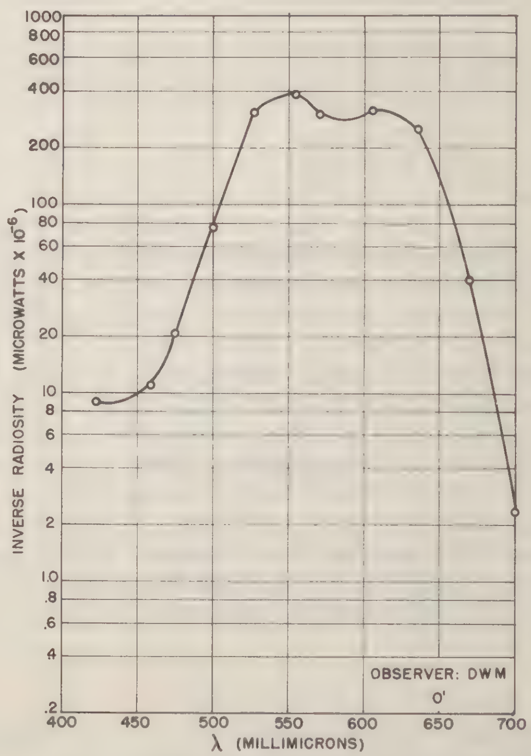

Figure 8. Point source spectral sensitivity data for observer DWM at the fixational center.

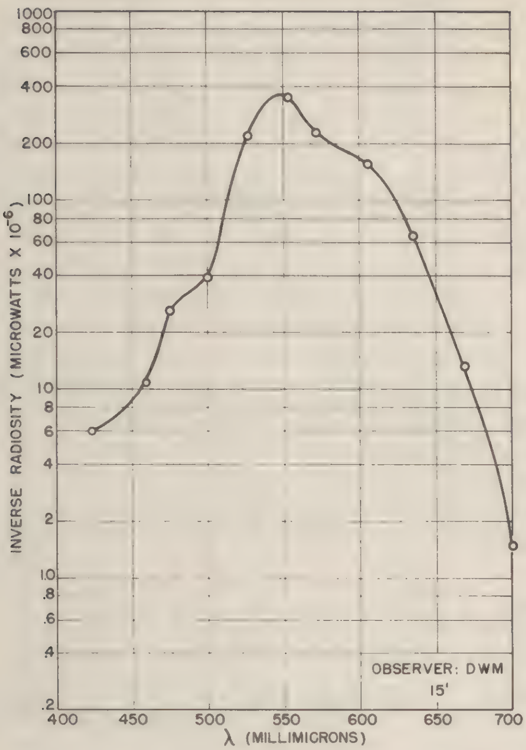

Figure 9. Point source spectral sensitivity data for observer DWM at a point 15 minutes from the fixational center.

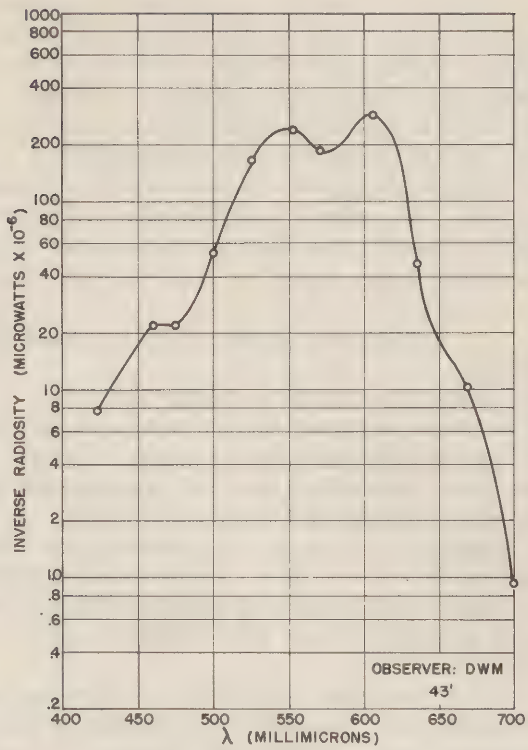

Figure 10. Point source spectral sensitivity data for observer DWM at a point 43 minutes from the fixational center.

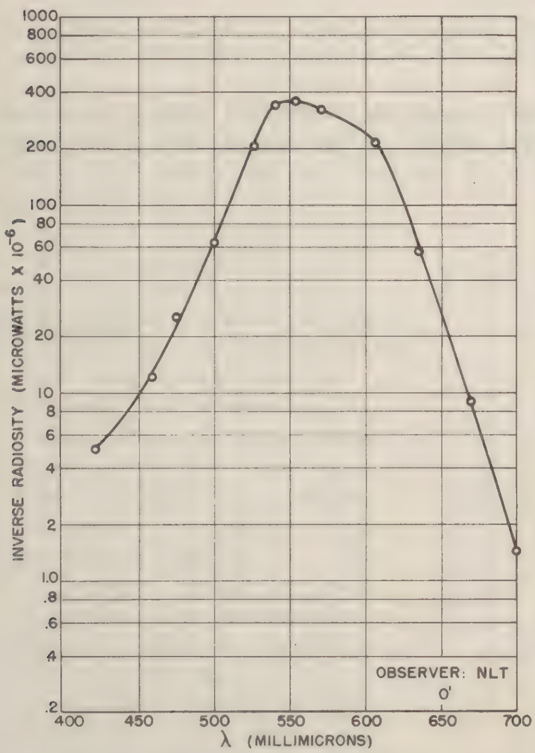

Figure 11. Point source spectral sensitivity data for observer NLT at the fixational center.

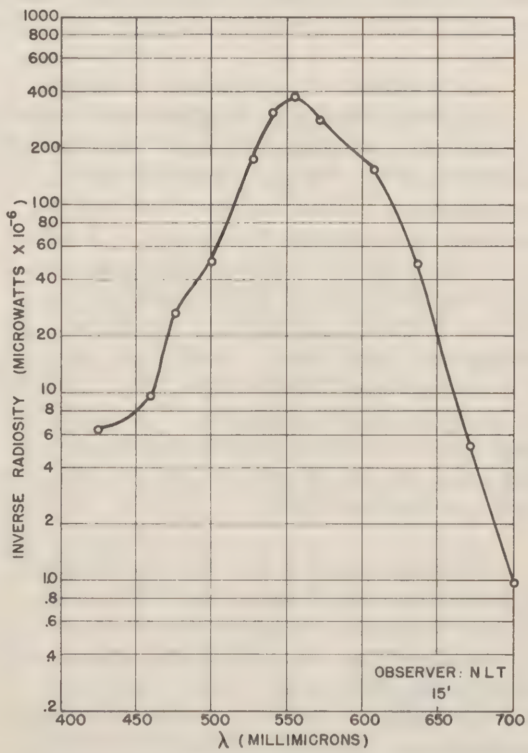

Figure 12. Point source spectral sensitivity data for observer NLT at a point 15 minutes from the fixational center.

The data are noteworthy for two features. First, the spectral sensitivity curves vary markedly from point to point in the eye of each observer; second, the curves vary markedly among observers. These data suggest that great caution be used in applying the usual color sensitivity (luminosity) data to the problem of specifying the detectability of colored point sources. We plan to obtain more complete data, and hope to identify the factors producing the changes in sensitivity from point to point in the same eye.

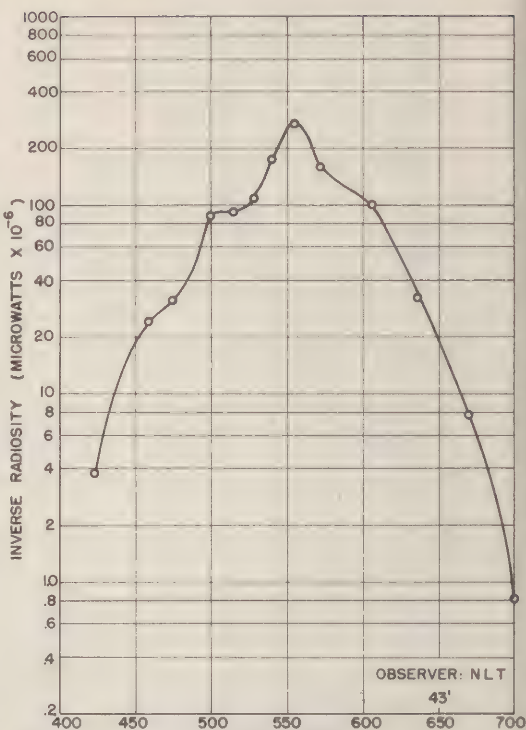

Figure 13. Point source spectral sensitivity data for observer NLT at a point 43 minutes from the fixational center.

c. Studies of target area for monochromatic targets

Experiments have been conducted to determine the relation between target size and detectability for circular monochromatic targets. These experiments have been completed for one wavelength only, 526 mμ. This experiment was conducted under the direction of Dr. George A. Austin two years ago. Measurements were made with a dark background. Monocular vision was used, with a 6 mm. artificial pupil. The target exposure time was 1/1000 second.

Data for one of the two observers are presented in Figure 14. We note that the data bear a general resemblance to the data in Figure 1, in which an analogous relation was obtained for white light stimuli at a background luminance of 10 foot-Lamberts. We hope to make similar measurements for various monochromatic wavelengths to specify the detectability of colored targets of various sizes.

d. Studies of peripheral sensitivity

All the Michigan studies thus far reported were conducted with the target occurring in the fovea of the visual field. We have in progress a study of the sensitivity of the near-periphery of the visual field to white point sources. The study is under the direction of Anne B. Moldauer. Eventually, we plan to study peripheral sensitivity for background luminances from zero to 75 foot-Lamberts. To date, the experiments have been completed only at three background luminances, 75, 1 x 10^{-1}, and 1 x 10^{-3} foot-Lamberts. At each background, measurements are made along each of the eight major meridians of the peripheral field.

Average values for all meridians are presented in Figure 15. We note that the threshold contrasts are least in the foveal center for all three values of background luminance. The extent to which peripheral thresholds exceed foveal thresholds is reduced markedly as background luminance is reduced from 75 to 1 x 10^{-3} foot-Lamberts.

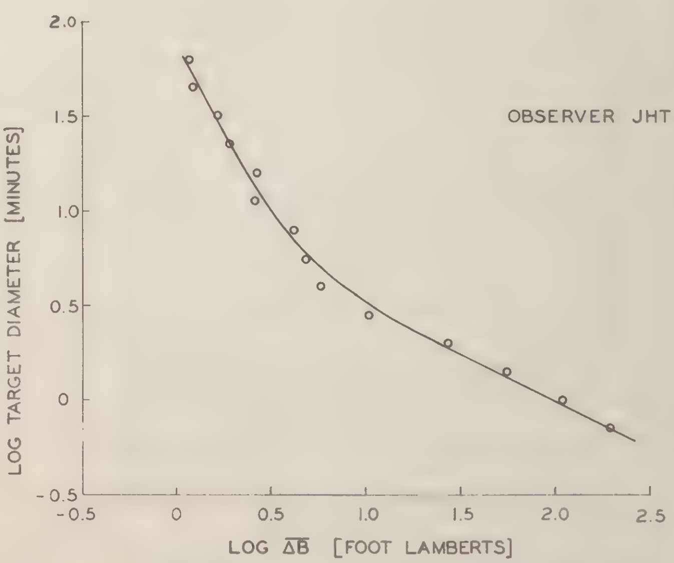

Figure 14. Data for circular target of wavelength 526mμ.

e. Studies of aircraft models

Thus far, all the experiments reported have been in the tradition of laboratory experiments employing relatively simple targets seen against uniform background luminances. We have adopted the philosophy that we should conduct this type of experiment to provide long-range answers to military visibility problems. However, in some cases it is essential not to wait as long for answers as would be necessary with the fundamental type experiment. In these cases, we expect to make threshold measurements using models of military targets of special interest. We have made a few model studies of aircraft already and we expect to make more of them as military urgency dictates. It is our plan to conduct these experiments in such a way that the maximum assistance can be given to our basic understanding of visual detection variables.

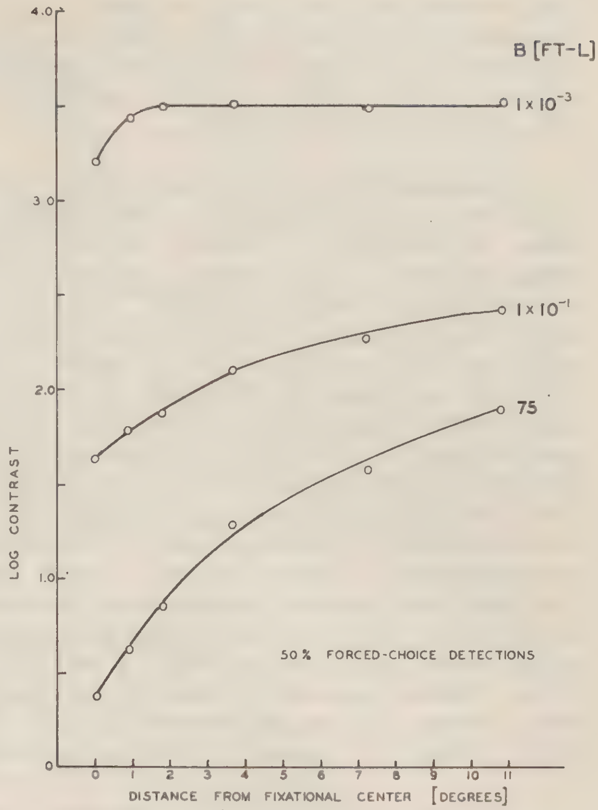

Figure 15. Point source thresholds for various points in the visual field. Average data for 2 observers.

f. Studies of psychological variables.

Three experiments have been conducted which represent studies of observer variables rather than physical variables of the target. These concern (1) the relation between awareness and forced-choice detections; (2) the effect of reduced information about the target; and (3) the effect of target frequency.

These experiments may be described briefly as follows.

(1) We have wondered to what extent military observers detect targets at as low contrasts as do our practiced laboratory observers when using the forced-choice procedure. To evaluate this question, we obtained threshold data on 8 practiced observers with the forced-choice procedure. The visual task was the detection of a point source with background luminance of 18 foot-Lamberts. We also had these observers determine thresholds under the same physical conditions using a "Yes" and "No" response. These results are reported in detail elsewhere.[2] The results of these two sets of measurements appear as the two curves to the left in Figure 16. The curve farthest to the left was obtained with the forced-choice procedure. The threshold contrast obtained with this procedure is arbitrarily set at 1.0 in Figure 16. The curve second farthest to the left was obtained with the Yes-No procedure.

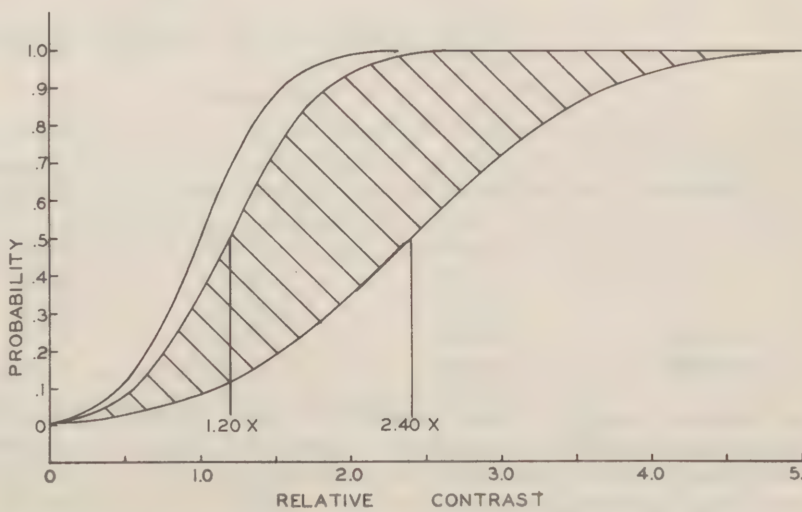

Figure 16. Point source thresholds for observers having different degrees of training. (See text for explanation.)

The average threshold contrast was 1.2 times the contrast obtained with the forced choice procedure. We believe that observers can never obtain lower thresholds when asked to evaluate their ability to detect than our trained observers can do. Hence, we believe that a factor of 1.2 is the minimum by which forced-choice thresholds should be multiplied to give thresholds of awareness.

Subsequently, 70 observers made visual detections under the same physical conditions, using the Yes-No procedure. When these observers were first introduced to the experiment, we told them: "We are going to turn on a light from time to time. If you see a light, say Yes. If you don't, say No." (We didn't tell them that there were blank trials.) If they asked, "How do I know?" we said, "Oh, you'll know when you try it." We tried to make them as naive as we possibly could and not to get them into the laboratory frame of reference. They knew where to expect the target and when to expect it. The average threshold for these 70 observers is given by the uppermost curve in Figure 16. Subsequently we trained these observers to use the Yes-No procedure to obtain as low thresholds as possible with it. Different groups of observers lowered their thresholds by different amounts but few lowered their thresholds as far as the curve second farthest to the left. Thus, the crosshatched area in Figure 16 represents the range within which Yes-No responses occur, depending upon the extent to which an observer has learned to be aware of the targets he is able to detect. When the observers began, their average threshold was 2.4 times the average forced-choice threshold. Some observers lowered their Yes-No threshold to 1.2 times the forced-choice threshold. For practical purposes, we believe that some factor lying between the 1.2 and the 2.4 should be used to convert from laboratory forced-choice detection probability to awareness. We believe that military observers vary widely within this range, depending upon the amount of practice they have had. We believe 2.0 is perhaps a conservative factor to use.

(2) Two years ago, we conducted a preliminary experiment to determine the extent to which reduction in information about the target influences target detectability. Mr. W. P. Tanner, Jr. was in charge of the experiment. Specifically, we wondered to what extent it mattered that observers knew when to expect a target. We also wondered to what extent it mattered whether observers knew how long the target was to be on or how large the target was to be. We measured target detectability under various conditions of information of these sorts. The results are presented in Table 2.

Table 2

THE EFFECTS OF TARGET INFORMATION

Threshold Contrasts

Observer	Warned	Unwarned	Unknown		
			Size	Duration	Both
1	.0091	.0127	.0122	.0131	.0143
2	.0120	.0210	.0190	.0203	.0182
3	.0171	.0197	.0258	.0276	.0227
Average	.0127	.0178	.0190	.0203	.0184
Factor	1.00	1.40	1.50	1.60	1.45

In Table 2, warned means observers were warned in the usual laboratory manner when the target was supposed to appear. Unwarned means the observers did not know when to expect the target, but it occurred as frequently on the average as when they were warned. We note that the thresholds are up by a factor of 1.4 when the observers are unwarned. The other three rows in Table 2 represent cases in which the observers did not know when to expect the target and, in addition, were not given information about its size and duration.

It wasn't just a matter of the observers' not knowing the size and duration; the size and duration were varied within the experimental session, being sometimes one size, sometimes another. For all practical purposes, if the observer does not know when to expect the target, taking away further information concerning the duration or size, or both, has very little, if any, additional effect. Hence, for practical purposes, lack of knowledge about the target's appearance seems to raise the threshold by a factor of approximately 1.5. Experiments are in progress to verify the relations found in these preliminary experiments, and to investigate the influence of removing knowledge as to where the target will appear.

(3) The final experiment measured the effect of target frequency upon target detectability. Nine observers were used in all. The observers were required to detect a point source with a background luminance of 5 foot-Lamberts. In one condition, designated frequent presentation, the targets appeared once in every 30 seconds, without warning. In a second condition, designated infrequent presentation, the targets appeared on the average twice in 20 minutes. The probability of Yes response was measured under each of these conditions. The results of the experiment are presented in Table 3. We note that, on the average, target detection probability decreases with infrequency of target presentation. A contrast factor of 1.2 is required to compensate this loss in detection probability.

Table 3

THE INFLUENCE OF TARGET FREQUENCY

Probability of Yes Response

	Stimuli	
Observer	Frequent	Infrequent
1	.81	.44
2	.80	.43
3	.89	.48
4	.74	.39
5	.63	.83
6	.50	.79
7	.74	.33
8	.69	.69
9	.76	.48
Averages	.73	.54
Contrast	1.00	1.20

We believe that these three experiments on psychological variables involved in target detection provide us with the kind of information required to convert laboratory data obtained with a forced-choice procedure into values suitable for use in the solution of military visibility problems. We intend to study these psychological variables under various conditions of target and background to provide conversion factors for various practical problems.

Discussion:

Dr. Duntley emphasized the fact that the seemingly academic factors which Dr. Blackwell had been discussing translate dramatically into military planning.

Dr. Fitts asked if Dr. Blackwell had any notion about the correction to be applied if a subject does not know where to look for a target.

Dr. Blackwell stated that a research program to establish this point was under way and that the answer should be available before too long. Dr. Blackwell guessed that the absence of knowledge where to expect a target might double the threshold contrast.

DISCUSSION OF CORRECTED EYEPIECES FOR NAVIGATION INSTRUMENTS

Col. Victor A. Byrnes referred to a request for information received from Col. Allen D. Smith, of the Office of the Surgeon General, USAF. Col. Smith's letter contained the following two questions:

1. Is there any information on the effect of uncorrected refractive error, either spherical or cylindrical, upon visual performance in navigational instruments such as sextants?

2. If the existence of refractive error is important, has an ophthalmic correction device for these instruments been developed?

Col. Byrnes made the following remarks in reply to the questions asked:

First, spherical errors are no problem in navigational devices, since the operator can focus the device to compensate for spherical error. Cylindrical errors cannot be corrected by focus devices, but these errors are not normally large in military personnel. Col. Byrnes stated that during the war someone developed a device for making cylindrical corrections in navigational devices. He inquired whether any of those present knew who developed this device. No one present was able to furnish any pertinent information. Col. Byrnes requested that, if anyone could locate any reference to this development, he contact the Executive Secretary.

ABSTRACTS

413. Lighting Pattern Distortion Caused by Rain on an Airplane Windshield
Tiedemann, Arthur T.
Civil Aeronautics Administration
Technical Dev. & Eval. Center
Indianapolis, Indiana
Tech. Dev. Report No. 189
January 1953 8 pp. (0)

"This report describes a limited series of observations to study the effectiveness of airport lights and light patterns when viewed through an airplane windshield during rainfall. It was found that the rain between the windshield and the lights being viewed caused some obscuration but little distortion. The visual distortion caused by the uneven surface of the water film on the glass was determined to be a function of the rate of water interception per unit area of the windshield. The water on the windshield tends to broaden the image of the lights, thus reducing the effectiveness of geometric patterns of lights and obscuring their positional relationship with respect to other elements on the airport.

"It was found that the maximum rainfall rate that can be tolerated without the use of windshield wipers is approximately one-half inch per hour, assuming an airplane speed of 120 miles per hour (mph). The use of an anti-wetting agent on the windshield greatly reduces the distortion and results in effectiveness of the lights at rainfall rates of two to three inches per hour."

414. A Review of Literature on the Relative Efficiency of the Dominant and the Non-dominant Eye
Gilinsky, Alberta S.
Columbia University
Wright Air Development Center
WADC Technical Report 52-13
January 1952 19 pp. (0)

"Evidence on the incidence of ocular dominance is summarized and the findings relevant to the comparative efficiency of the dominant and the non-dominant eye in various perceptual-motor skills and visual functions are reviewed. Although a small advantage for the dominant eye in cases of unmixed manual-ocular laterality is indicated by some studies, there is reason to doubt the permanence and universality of this superiority. No advantage for either eye is found in cases of mixed laterality for any function."

415. A study of the Requirements for Letters, Numbers, and Markings to Be Used on Transilluminated Aircraft Control Panels—Part 4—Legibility of Uniform Stroke Capital Letters as Determined by Size and Height to Width Ratio and as Compared to Garamond Bold
Brown, Fred R.
Naval Air Material Center
U.S. Naval Base, Philadelphia, Pa.
Report TED No. NAM EL-609 Part 4
10 March 1953 20 pp. (0)

"The experiments described in this report were designed to determine the effect of variations in size and in height-to-width ratio upon the legibility of capital block letters as

they would be used on aircraft cockpit plastic lighting plates. In addition, a font of Garamond Bold capital letters characterized by variable height-to-width ratios, serifs, and non-uniform stroke-widths was used. Tests with letters differing in these form characteristics were conducted, using two exposure durations and five levels of red transillumination which simulated the conditions of night viewing of the plastic lighting plates. Using the same letter form variables, tests were conducted with simulated daylight illumination of two levels and employing a single duration of exposure.

"Results of tests with capital block letters .12, .13, .14, .156, .17, and .18 inches in height with a height-to-width ratio of 1 to 1 indicate that within test limits the larger the letter is, the more legible it becomes. The results from tests of block capital letters .156" in height with height-to-width ratios of 1.81, 1.43, 1.17 and 1.00 reveal that under night viewing conditions, within tests limits, the wider the letter is, the greater is its legibility. With simulated daylight illumination, there is some evidence that increased letter widths produce a decrement in legibility after some optimal height to width ratio has been attained. With the Garamond-Bold font under transillumination, it is indicated that this font is somewhat more legible than the narrowest capital block letters, but that as the width of the capital block letters is increased, they become more legible than those of the Garamond-Bold font. In general, with simulated daylight illumination, the capital block letters are more legible than those of the Garamond-Bold font. Recommendations are made for letters to be used on plastic lighting plates."

420. Comparison of Two Visual Warning Systems in Aircraft
Spencer, J.
RAF Institute of Aviation Medicine
Flying Personnel Research Committee
Farnborough, England
FPRC 790
June 1952 3 pp. (0)

"An airborne comparison has been made between two types of systems for presenting visual warnings of certain types of failure that are likely to occur in aircraft. The experiment involved 10 pilots who had to complete a low level cross-country flight in a Harvard IIb aircraft while responding to the artificially produced warnings. In one case, warnings were dispersed around the instrument panel, in the other, they were centralized on a 'warning panel' which included two flashing, attention-getting lights.

"Using as criterion the response time between exposing the signal and executing the correct response, the centralized warning system was superior (statistically significant at p = .05 level). The average response time to the central warning system was 66% of the average response time to the dispersed warning system."

Note: This report is not available in the Vision Committee files. However, one copy is available in the library of the Naval Research Laboratory, Washington, D. C.

421. The Influence of Surround on Tracking Performance. Part 1. Tracking on Combined Pursuit and Compensatory One-Dimensional Tasks with and Without a Structured Surround
Senders, John W.
Aero Medical Laboratory
Wright Air Development Center
Wright-Patterson AFB, Dayton, Ohio
WADC Tech. Report 52-229, Part 1
February 1953 13 pp. (0)

"Four groups of subjects performed a series of tracking tasks on two different target courses and under two conditions of surround illumination. The tasks were varied from pure compensatory to pure pursuit (following) tracking. In general, performance was superior with either surround illumination with a 50 or higher percent of pursuit component. However, the interactions between target course rates, surround illumination, and percent pursuit component in the task are large and complex.

"This is the first of a series of studies on the same subject."

422. Determination of Width and Luminance of a Cathode-Ray-Tube Trace
Ranken, Howard B.
Columbia University
Wright Air Development Center
Wright-Patterson AFB, Dayton, Ohio
WADC Tech. Report 52-258
September 1952 10 pp. (0)

"A method is described for specifying cathode ray tube (CRT) traces in terms of visual measures of width and central luminance. Trace width is measured with an image doubler which produces two parallel images of the CRT trace; width is defined in terms of the distance between the centers of the two images when they just appear to merge. Central luminance of the trace is measured with a magnifying system in conjunction with the Macbeth illuminometer. The magnifier produces a real image of the trace sufficiently enlarged to fill the field of the Macbeth. Matching is performed in the usual way, and the appropriate conversion factor applied to the Macbeth reading. Estimates of intra-observer and inter-observer variability are given for width and luminance measures. The method of measuring central luminance is compared experimentally with an alternative method involving a direct monocular match."

423. Psychophysical Research Summary Report 1946-1952
Psychophysical Research Unit
Mount Holyoke College
South Hadley, Mass.
Tech. Report SPECDEVCEN 131-1-5
January 1953 194 pp. (0)

"This report is a compilation of more than seventy experiments in the area of visual discrimination. Such topics as estimating bearing, estimating the number of targets, coding of controls, etc., are covered.

"In compiling the data it became evident that some of the results have immediate specific military application, some have general application, and others provide basic research information. Because of this, it was not feasible to present these results with specific recommendations for incorporating them into military training and equipment problems.

"As a result, this report is primarily written for the military psychologist who will undoubtedly have many opportunities, now and in the future, to employ these research answers."

424. <u>Report on Testing and Evaluation of Bausch and Lomb Neutral N-15 Sunglasses</u>
Memorandum Report 53-3
Medical Research Laboratory
U.S. Naval Submarine Base
New London, Conn.
5 March 1953 4 pp. (0)

"A sample lens of the Bausch and Lomb N-15 sunglasses was given a battery of tests in this laboratory. The glass has been found to meet all requirements for general purpose sunglasses recommended by this laboratory. The spectrophotometric transmittance curve and the Judd average deviation index show that the lenses used in these glasses are very nearly flat neutral, thus insuring daylight duplication of colors. The high absorption of heat radiation is especially desirable in many naval and air situations."

425. <u>Use of Word-Frequency Tables in the Preparation of Labels</u>
Directorate of Research
Aero Medical Laboratory
Wright Air Development Center
Wright-Patterson AFB, Ohio
Tech. Memorandum Report WCRD 52-98
3 November 1952 5 pp. (0)

"Recognition of labels is considered in the light of evidence that the time for which a word must be exposed in order to be recognized with a specified error depends upon the word's average frequency of occurrence. Tables of average word frequencies are recommended for use in preparation of labels and standard operating procedures. Limitations on the use of the tables are discussed."

426. <u>Judgment of Height by the Apparent Obliquity of Familiar Ground Outlines</u>
Spencer, J.
RAF Institute of Aviation Medicine
Flying Personnel Research Committee
FPRC 819
March 1953 13 pp. (0)

"A series of laboratory experiments was performed to assess the accuracy with which people can judge their height when the judgment is based upon an obliquely-regarded familiar shape. Measures were taken employing binocular and monocular vision.

"Under the experimental conditions, the operation of a bias, known as a constancy effect—i.e., a tendency to underestimate the actual amount of perspective in this case—upon

judgments is demonstrated. This occurred with binocular and monocular vision. The magnitude of the effect is dependent upon the actual obliquity of the pattern.

"Furthermore, the magnitude of the constancy effect depends upon the general illumination of the figure and its background. Decrease of illumination leads to a reduction of the magnitude of the constancy effect irrespective of whether monocular or binocular vision is being employed. The actual magnitude of this constancy change is small (13% reduction expressed as a percentage of the actual physical height from which the judgments are made) but it has statistical significance. The illumination range producing this change is approximately 66:1.

"The explanation and significance of the effect are discussed with particular reference to the part that might be played by the effect when alternating day and night landing are performed by pilots."

427. <u>A Comparison of an Auditory Warning System with a Controlled Visual Warning System for Use in Aircraft</u>
Spencer, J.
RAF Institute of Aviation Medicine
Flying Personnel Research Committee
FPRC 818
March 1953 7 pp. (0)

"In a previous report (FPRC 790) the results of a comparison between two types of visual warning presentation were described. In the present report the comparison is between a presentation of auditory warning information and a visual centralized panel lay-out. The latter presentation with attention-getting flashing lights is the same as that described in FPRC 790.

"Three warnings were used on each system, due to the fact that in this experiment the auditory warning equipment was limited to three different sounds. Ten pilots had to complete a low-level, cross-country flight in a Harvard IIb aircraft during which time they responded to warnings on both systems.

"The criterion adopted was the time elapsing between the onset of a warning and the completion of the correct response by the pilot. The average response time for the auditory presentation was 5.04", and for the visual presentation, 5.68", the difference between the two figures being statistically insignificant. The difference between the average range of response times for the two systems is also very small."

428. <u>Accommodation of the Human Eye in an Empty Visual Field</u>
Whiteside, T. C. D., and F. W. Campbell
RAF Institute of Aviation Medicine
Flying Personnel Research Committee
FPRC 821
March 1953 9 pp. (0)

"1. An empty field is defined as one in which there is no cue upon which ordinary accommodation can act.

"2. A method is described for recording photographically the change in curvature of the anterior surface of the lens during accommodation.

"3. This method was employed to study the behaviour of accommodation when viewing an empty field at photopic and at scotopic levels.

"4. It is found that in an empty field of brightness 200 foot-Lamberts, a mean of 0.5 dioptres (5 subjects) of accommodation is involuntarily exerted.

"5. In scotopic conditions a mean of 0.6 dioptres (12 subjects) is involuntarily exerted.

"6. It is suggested that the position of rest of accommodation is not for infinity but for a distance of approximately one metre from the emmetropic eye.

"7. This 'day myopia' may reduce visual efficiency in fog or in flight at high altitude.

"8. The modifying effect of depth of focus upon day myopia is discussed."

429. <u>The Rate of Handling Information—Key Pressing Responses to Light Patterns</u>
Klemmer, Edmund T. and Paul F. Muller, Jr.
Human Factors Operations Res. Lab.
Air Res. & Dev. Command
Bolling Air Force Base
Washington 25, D.C.
HFORL Memo Report No. 34
March 1953 11 pp. (0)

"Several tests were given to determine the rate of transmission of information through the human channel when the information was encoded for presentation in flashing lights and the operator's output was the pressing of corresponding keys. The independent variables were the rate at which the lights were flashed (two to five per second), and the number of bulbs which might be lighted in the stimulus (one through five). All possible stimulus bulbs were equally probable and any number could be lighted simultaneously. In addition to these forced rate tests, the five bulb test was given as a self-pacing test.

"The main results of the experiment were as follows:

"1. Increasing the stimulus presentation speed increases the information transmission rate only up to a point where the subject is making a few errors. Further increases in presentation speed result in large decreases in informational transmission.

"2. Increasing the number of possible light bulbs in the stimulus from one through five more than tripled the maximum informational transmission rate.

"3. In the range of speeds from two to five per second the reaction time is not a function of stimulus presentation rate.

"4. The reaction time increases with the number of possible light bulbs in the stimulus but is not a linear function of the information presented in the range from two to five stimuli per second.

"5. The stimulus presentation speed at which maximum transmission occurs is very close numerically to the reciprocal of the reaction time for that test.

"6. The self-pacing test results in as high information transmission as the maximum reached in the forced rate tests.

"7. The subjects could put out information with the key pressing response at a rate double that of their ability to transmit information from the flashing lights."

430. <u>Visibility—A Bibliography</u>
Library of Congress
Technical Information Div.
Washington, D. C.
July 1952 90 pp. (0)

This bibliography was prepared at the request of the Vision Committee. A limited number of copies may be obtained from the Executive Secretary.

431. <u>Search Area and Target Detectability on a PPI Cathode-Ray Tube</u>
Buckley, Barbara Beach, Randall M. Hanes, and James Deese
Johns Hopkins University
Wright Air Development Center
Wright-Patterson AFB, Ohio
WADC Tech. Report 52-303
April 1953 12 pp. (0)

"The present experiments investigated the effect upon detection thresholds of small signals on a 7-in. PPI radar scope of viewing only a portion of the scope rather than the whole scope. If there is a search factor in detection, it would be expected that viewing only a portion of the scope would result in lower thresholds. Two methods of dividing the scope were used. In one method the observer viewed either the right or left sector. In the other method the observer viewed the outer or inner portions (dividing the radius in half). Thresholds for detection of small targets under these conditions were compared with thresholds obtained with search of the whole scope. The location of targets was randomized so that observers could not predict where they would appear.

"When the unused portion was masked by black paper the thresholds for the outer-inner division were significantly lower than those for the whole scope or for right-left division. Right-left division was not different from search of the whole scope. When the unused portion of the scope is not masked or when two observers are used simultaneously searching different parts of the same scope, there is either no difference or a very small difference between use of part of the scope and use of the whole scope. Thus it seems that only when the unused portion of the scope is masked off is search of part of the scope better than search of the whole scope."

432. <u>An Experiment on Dial Coding</u>
Cohen, Jerome, and Virginia L. Senders
Antioch College
Wright Air Development Center
Wright-Patterson AFB, Ohio
WADC Tech. Report 52-209
September 1952 16 pp. (0)

"Three equated groups of subjects were tested over a five-day period on their ability to locate and check-read an instrument on a simulated instrument panel. On the sixth day, the locations of the instruments on the panel were changed, and the subjects were asked to locate instruments on the rearranged panel. The control group was tested on a panel on

which all thirty-two instruments were identified only by labels; another group was tested on a panel on which instruments were, in addition, identified by a color code; and a third group was tested on a panel on which instruments, besides being labeled, were identified by a shape code. Except on the early trials, the control group was slower and more variable than either experimental group, and made more errors in locating instruments. Differences between the experimental groups and the control group were greatest for the rearranged panel. The color-code group showed, in general, a better performance than the shape-code group. From these results it is concluded that coding will improve dial checking performance, but a formal system of coding may not be necessary, since differences in labels, graduations, and numerals already form a code."

433. The Visibility of Submerged Objects
Duntley, S. Q.
Visibility Laboratory
Mass. Institute of Technology
31 August 1952 74 pp. (0)

This publication is the final report of the research program of the Visibility Laboratory operating at the Massachusetts Institute of Technology. (The Visibility Laboratory has been transferred to the Scripps Institution of Oceanography at the University of California and the research continues at the new location.) The research reported concerns determination of the physical factors which influence the visual detectability of objects submerged in the ocean.

Chapter headings in the report are as follows: (I) The Apparent Contrast of Submerged Objects; (II) Principles of Hydrological Optics; (III) The Inherent Contrast of Submerged Objects; (IV) A Water Clarity Meter; (V) An Atmospheric Clarity Meter; (VI) Visibility from Aircraft; (VII) Contrast Reduction by the Atmosphere.

434. On the Phenomenon of the Colored Sun, Especially the "Blue" Sun of September 1950
Penndorf, Rudolf
Air Force Cambridge Research Center
AFCRC Tech. Report 53-7
April 1953 41 pp. (0)

"The phenomenon of a colored sun or moon can be explained by Mie's theory of large particle scattering, if the radius of such particles is of the order of the wavelength of light.

"Smoke generated by large forest fires in Alberta, Canada, traveled across the Atlantic. In many places in the eastern United States and especially over large parts of Europe, the sun, moon and stars were seen blue in color in September 1950. Using Mie's theory and some extinction measurements, the radius of the particles is calculated to be between 0.5 and 0.8 μ and the concentration $175/cm^3$ and $127/cm^3$. The total amount in the smoke layer is about 4.7 to 6.5 x $10^7/cm^2$ column. Three size spectra are assumed, case 1 deals with a uniform size, cases 2 and 3 with a Gaussian distribution of the size spectrum. The refractive index for water droplets is chosen, but it is also studied carefully for other substances. The radius becomes larger for ice at low temperatures and smaller for pure smoke; the total number varies inversely to the radius, but the extinction coefficient remains unchanged. Scattering by spherical particles is assumed, because the shape plays a very minor role. For anisotropic particles, the extinction coefficient increases by less than 10 percent.

"The intensity distribution of the solar spectrum is calculated between 3500 Å and 7000 Å after passing through the smoke layer. The computations show that a pronounced maximum of the solar spectrum occurs around 4100 Å and 4600 Å in all the cases considered. The physiological impression of such a spectrum is bluish. It could be shown that the 'blue' sun observed during dust storms can be explained in the same way if the radius of the quartz particles is about 0.3μ and a total number $< 10^8/cm^2$. Finally the hypothetical case for a 'green' sun is calculated. The computations show that this phenomenon can occur only for a narrow Gaussian distribution of particles and this explains the rareness of the phenomenon."

435. Selective Spectrum Lighting for CIC Areas
Human Eng. Br., Human Factors Div.
U.S. Navy Electronics Lab.
San Diego, Calif., Report 337
17 November 1952 7 pp. (R)

"Conclusions: 1. Two Selective Spectrum Lighting (SSL) systems have been examined and found practicable for CIC operations. One uses a sodium-vapor lamp for ambient lighting, with didymium filters for CRT displays; the other utilizes a mercury-vapor lamp with Noviol and red filters and a long-persistence phosphor in the CRT's. In both systems the filters absorb only the wavelengths of the ambient light source, providing an undisturbed view of the displays.

"2. Ambient light levels may be maintained at 1- and 2-foot candles without disturbing CRT visibility.

"3. Contrast ratios of the CRT presentation in these systems are greater than those obtained with present lighting practices.

"4. SSL systems provided improved conditions for maintenance and inspection of gear, reading and writing of messages, free and safe movement of personnel, and operation of equipment controls."

436. Twilight and Airglow Study
MacKenzie, Merlin H., Frederick F. Kohls, Harold E. Cronin, and S. L. Seaton
Geo-Science, Inc.
Air Force Cambridge Research Center
February 1, 1953 90 pp. (0)

"A summary of administrative actions, personnel, and correspondence is given. Electrophotometric recordings of zenith sky brightness in the visual range near Washington, D.C., in the form of continuous traces, have been made throughout essentially all of the two-year interval embraced in this final report. The first recordings were devoted to examination of moonlight. Later, the moonless sky was also studied, and finally the twilight was included in the investigations. In the final months of the program, the zenith light was recorded from just before sunset throughout the entire night until just after sunrise. This immense range in light intensity, almost six orders of magnitude, was accommodated by two electrophotometric systems held under continuous control by automatic calibrating devices having an accuracy of somewhat better than plus or minus three percent throughout the entire range. Light values are given in standard photometric units in Appendices A and B; forming a part of this report. A brief summary of instrumentation used is outlined, together with a discussion of calibrations. Trace types adopted are identified and the relationship of

local meteorological conditions with trace type is discussed. Variations of zenith light intensity in the presence of moonlight, corrected to full moon, show a seasonal variation independent of moon altitude such that the zenith light intensity is greater in summer than in winter by about a factor of two. It is suggested that this effect may be caused by greater water vapor content or condensation nuclei count in the atmosphere overhead in summer than in winter. Night sky light in the zenith, while showing the expected variations in concert with passage of the galactic plane through the meridian, shows no general correlation with magnetic activity as measured by K-index. Mean values for morning and evening twilight are shown in graphical form. The difference between morning and evening twilight is pronounced and shows the ratio of morning to evening twilight to be about 1.2 for shadow-heights above 150 km. It is suggested that this phenomenon may be caused by cooling of the atmosphere at night in such a way that the atmospheric density is greater to about 90 km and less above 150 km in the morning than in the evening. Ratio of intensity of light from the star Vega to the background night sky light has a mean value of about 12 for an effective aperture of 3.2 degrees in the recording system."

437. <u>Eye Dominance and Tracking Performance</u>
Gilinsky, A. S. and J. L. Brown
Columbia University
Wright Air Development Center
WADC Tech. Report 52-15
April 1952 15 pp. (0)

"This report describes an experiment which compares the relative efficiency of performance with the dominant eye and performance with the non-dominant eye in a compensatory tracking task. With practice confined first to one eye, then to the other, subjects attempted to keep a target light in position by compensating for random movements applied to it from an outside source. Measures of time on target and errors per trial were analyzed for the influence of eye dominance upon initial tracking skill and upon the acquisition of the tracking skill and the transfer of training from one eye to the other. No significant differences between the results with the dominant eye and those obtained with the non-dominant eye appeared on the first trial. A small differential practice effect in favor of the dominant eye was found for the first half of training. Initial training with either eye was found to improve the subsequent activity with the untrained eye. The performance of the group using the non-dominant eye was consistently superior to that of the group using the dominant eye during later training. Therefore it cannot be concluded that the dominant eye is superior to the non-dominant eye in a compensatory tracking task."

438. <u>A New Method of Producing Continuously Variable Magnification with an Optical System</u>
Fry, Glenn A.
Ohio State University Research Foundation
Wright Air Development Center
WADC Tech. Report 52-279
October 1952 4 pp. (0)

"A new method of producing continuously variable magnification with an optical system is described. A reciprocal function is obtained mechanically with the use of cables and pulleys."

<u>Note:</u> A few copies of this report are available for distribution from the Secretariat.

439. <u>A Study of the Requirements for Letters, Numbers and Markings to be Used on Trans-illuminated Aircraft Control Panels. Part 8— A proposal for the Standardization of Aircraft Electrical and Electronic Control Knobs.</u>
Crumley, L. M.
AMEL, Naval Air Experimental Station
Philadelphia, Pa.
Report XG-T0192
28 April 1953 10 pp. (0)

"A study of the present status of aircraft electronic and electrical knobs has indicated the desirability of improvement. Of the methods suggested for accomplishing this improvement, the adoption of a relatively small, standard set of gray colored knobs with provisions for transillumination where needed appears to meet the requirements better than any of the other suggested methods such as shape and/or color coding to indicate function. The AMEL knob series is considered to meet many of the requirements discussed and to be suitable in many respects in place of hundreds of existing knobs."

440. <u>Final Approach Visibility Studies—Part II</u>
Weather Bureau, U.S. Dept. of Commerce
Project 4.14, Air Navigation
Development Board
Washington, D.C.
March 1953 53 pp. (0)

This is the second report of progress on the Weather Bureau project concerned with visibility during the final approach of landing aircraft. Topics covered include visibility observations, transmissometer measurements by day and at night, and studies of the height of cloud base.

441. <u>Luminance Thresholds for the Resolution of Visual Detail During Dark Adaptation Following Different Durations of Light Adaptation</u>
Diamond, Aaron L., and Alberta S. Gilinsky
Columbia University
Wright Air Development Center
Wright-Patterson AFB, Ohio
WADC Tech. Report 52-257
April 1952 21 pp. (0)

"Luminance thresholds for the visual resolution of various widths of alternating light and arc lines were determined at various times during recovery from different durations of light adaptation. Increasing duration of preadaptation from one second to five minutes raises the initial dark adaptation thresholds and decreases the speed of the recovery process. The level of visual acuity determines the range of luminance covered by the dark adaptation curves."

442. Reports of Research in the Field of Engineering Psychology
Christensen, Julien M. and Harry R. Collins
Aero Medical Laboratory
Wright-Patterson AFB, Ohio
WADC Tech. Report 53-75
April 1953 25 pp. (0)

"This bibliography lists by functional groupings the authors and titles of the reports published by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, since its inception in 1945."

443. The Effects of Two Instrument Lighting Systems on Dark Adaptation
Wilcox, Lawrence R., and Edward L. Cole
Aero Medical Laboratory
Wright-Patterson AFB, Ohio
WADC Tech. Report 52-263
December 1952 15 pp. (0)

"Four pilots with normal vision were tested for the effects of the standard indirect red and red-flood aircraft lighting systems on dark adaptation. Data were gathered in a completely blacked-out cockpit while the aircraft was in a hangar and also during conditions of normal night flight. Significant differences in dark adaptation thresholds were found between the hangar and flight phases and between the low and high levels of light intensity used. No significant differences were found between the types of lighting systems used. It is concluded that the flight conditions of starlit night sky affect dark adaptation levels to a significant degree."

444. The Effect of Number of Dials on Qualitative Reading of a Multiple Dial Panel
Senders, Virginia L.
Antioch College
Wright Air Development Center
Wright-Patterson AFB, Ohio
WADC Tech. Report 52-182
November 1952 34 pp. (0)

"Three experiments are reported in which the time required to make qualitative readings of a panel of dials was determined as a function of the number of dials on the panel. The results indicate that reading time is approximately a linear function of number of dials on the panel. The slope of the line is about eighteen times greater when pointers are not aligned than when they are aligned at the nine o'clock position.

"For aligned pointers, time increases directly with the distance of the misaligned pointer from the fixation point, either vertical or horizontal. When pointers are not aligned, time bears no regular relation to horizontal distance from fixation point, but increases regularly from top to bottom of panel. From these differences, it is hypothesized that the quantitative difference between performance under the two conditions may be due to qualitative differences in the manner of scanning the panel.

"Practice effects are very large, and it is hypothesized that these may be due at least in part to the expansion of the visual form-field."

445. A Study of the Requirements for Letters, Numbers and Markings to be Used on Transilluminated Aircraft Control Panels. Part 7--An Evaluation of the Relative Manipulability of Simple Toggle Switches, Cutler-Hammer Lock-Lever Toggle Switches and Toggle-Switch, Switch-Guard Combinations
Crumley, Lloyd M.
AMEL, Naval Air Exper. Station
Philadelphia, Pa.
Report TED No. NAM EL-609, Part 7
16 February 1953 18 pp. (0)

"An investigation has been conducted to determine the relative manipulability of a simple toggle switch, a toggle switch-switch guard combination, and a Cutler-Hammer Lock-Lever type toggle switch. It has been shown that if hand to switch and/or guard contact time is utilized as a criterion of manipulability, the Cutler-Hammer Lock-Lever type toggle represents an intermediate manipulability step between simple toggles and toggle-guard combinations.

"It has also been demonstrated that replacement of the present 'lock-lever' head with a 1/2" by 1/2" knurled cylinder significantly decreases the manipulation time.

"An examination of the data collected for the above evaluations has revealed that the ambient light level has a significant effect on manipulation time, as does practice. It also shows that under the conditions tested simple toggles are actuated more readily from the 'up' to the 'down' position but that 'lock-lever' switches, which require equivalent upward and downward actuation motions are actuated more readily from the 'down' to the 'up' position. This reversal is considered the result of the more complicated approach and actuation motions required by the 'lock-lever' type switch."

446. Slant Visibility
Penndorf, Rudolf, B. Goldberg, and D. Lufkin
Air Force Cambridge Research Center
AF Surveys in Geophysics No. 21
December 1952 49 pp. (0)

"The following survey is an attempt to present the slant visibility problem in a form and language suitable for direct field use. The scientific background information is confined to the appendix. The survey is based on the available knowledge of background material without acquiring new information by special research investigation. For this reason several simplifying assumptions had to be made.

"After defining the terminology used in this survey, slant range visibility is computed in section 4 for typical cases, namely a standard clear atmosphere, an atmosphere with a thin fog layer on the ground and two different kinds of visual ranges above the fog layer, and finally a thick duet layer imbedded into the atmosphere between 6,000 and 7,000 ft.

"The influence of the position of the sun in the sky on the visibility horizon is discussed in section 5. The slant visual range is reduced considerably, if the observer is looking towards the sun (up - sun) as compared to other directions. Moreover, the slant visual range is shorter as the position of the sun above the horizon becomes lower. The influence of city smoke as a function of the wind direction is then discussed. It has been observed that the visibility horizon down wind over cities is also reduced considerably.

"In section 6 the slant visual range observation from 45,000 ft. is considered indicating the importance of contrast seeing.

"It cannot be said that the state of our knowledge concerning slant visibility is satisfactory. The background information is not complete, and measurement problems exist. The importance of the human factors, i.e., physiological, psychological, and ophthalmological effects on seeing, cannot be overlooked and they need further investigation. It will come as no surprise, therefore, that verification of some of the numerical results presented in the text is not yet complete. Nevertheless, they are given here because they represent the best usable solutions available. Furthermore, since the actual atmosphere at a given place and at a given time is far from a standard atmosphere, nomograms for each case would be necessary. This is an impossible task for the computer, and it would only irritate the man in the field. Therefore, this approach yields only qualitative results. In most field applications, however, qualitative results give sufficient information to make the necessary decisions."

447. The Effect of Different Preadapting Luminances on the Resolution of Visual Detail During Dark Adaptation
Brown, John Lott
Columbia University
Wright Air Development Center
Wright-Patterson AFB, Ohio
WADC Tech. Report 52-14
July 1952 27 pp. (0)

"Luminance thresholds for the resolution of various widths of grating line were determined during dark adaptation following light adaptation to luminances of 11,200, 1290, 100, and 0.98 millilamberts. Dark adaptation curves for the finest gratings, representing high visual acuity, start at a high initial luminance and drop to a final steady level after 5 to 12 minutes in the dark, as is characteristic of cone function. Curves for coarser gratings may display both cone and rod portions, or after light adaptation to low luminances may represent rod function only. The higher the degree of resolution required the higher the position of the dark adaptation curve with respect to the log threshold luminance axis. Increasing the level of light adaptation results in higher initial threshold luminances and a more gradual decline to a final steady value. The final steady value of threshold luminance for a given value of acuity is little influenced by the level of light adaptation.

"These results are of practical importance in many Air Force situations. Consider, for example, the radar bombardier who may have to shift his attention from levels of high illumination (sunlit clouds) to levels of low illumination (radar scopes). Complete recovery of cone acuity may require as much as five minutes, although fairly adequate acuity returns within one minute. As long as the brightness differential is limited to a ratio of 500 to one or less, acceptable visual acuity is recovered within one second. As the brightness ratio increases above 500 to one, the immediate loss in acuity in shifting to the lower brightness levels increases rapidly. From these data it is possible to specify the brightness differentials that can be tolerated in the performance of many common Air Force tasks."

448. Interior Color Schemes for Aircraft Gray Instrument Panel
Vanderplas, James M.
Aero Medical Laboratory
Wright-Patterson AFB, Ohio
Tech. Note WCRD 53-71
June 1953 7 pp. (0)

"This report constitutes a discussion of visual adaptation factors affected by the use of gray as a color for aircraft instrument panels. A summary and discussion are presented of considerations, evolved at recent mock-ups and conferences at the Wright Air Development Center, of factors of aircraft instrument panel brightnesses as they affect instrument reading and exterior visibility. It is concluded on the basis of these considerations that a gray color, number 3520 in Federal Specification TT-C-595 is suitable as a color for instrument panels from the standpoint of visual adaptation requirements."